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### (54) EXPERT SYSTEM WITH PROCESS CONTROL

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**Description**BACKGROUND OF THE INVENTION5 Field of the Invention

[0001] The present invention relates to expert systems (also known as knowledge-based systems), to process control systems, and to hybrids thereof.

10 Discussion of Related Art

[0002] Various known teachings which are believed to be related to the various embodiments disclosed in the present application will now be discussed. However, applicant specifically notes that not every idea discussed in this section is necessarily prior art. For example, the characterizations of the particular patents and publications discussed may relate them to inventive concepts in a way which is itself based on knowledge of some of the inventive concepts. Moreover, the following discussion attempts to fairly present various suggested technical alternatives (to the best of applicant's knowledge), even though the teachings of some of those technical alternatives may not be "prior art" under the patent laws of the United States or of other countries. Similarly, the Summary of the Invention section of the present application may contain some discussion of prior art teachings, interspersed with discussion of generally applicable innovative teachings and/or specific discussion of the best mode as presently contemplated, and applicant specifically notes that statements made in the Summary section do not necessarily delimit the various inventions claimed in the present application or in related applications.

25 Process Control Generally

[0003] To compete in global markets, manufacturers must continually improve the quality and cost of manufacture of their products. They must do this in the face of changing market needs, changing raw materials costs, and reduced staffing. Automatic computer control of the manufacturing process can play an important part in this, especially in the chemical process industry. Most process plants already have the basic automatic regulating controls (low level controls) needed to control the plant at a given operating point. These provide the foundation for higher level supervisory controls (referred to here as supervisor procedures or supervisors) that seek to improve quality, reduce cost, and increase plant uptime by moving the plant to a different operating point. These changes can be made directly via the lower level controls, or indirectly via the plant operator.

[0004] Although supervisory controls have been in use for years, they have lacked a number of desirable features. To best improve quality and cost, a supervisor procedure should:

- help control the quality of the end product;
- reduce the cost of operating the plant;
- help avoid unnecessary upsets or shutdowns;
- work effectively with plant operators;
- act in concert with standard operating procedures; and
- be supportable by plant operating and support people.

[0005] To measure quality, a supervisor procedure should ideally have access to measurements of the basic properties of the product which affect its value and usefulness to the customer. Since most product properties measurements are sampled (and are measured in a laboratory), the supervisor should have access to a historical process database which can store these measurements as well the basic process data from the lower level control systems. Since sampled measurements and the process itself normally include some components of random variation, the supervisor should include statistical tests which can determine if a sequence of sampled measurements is varying normally around its aim value (i.e. is "on aim"), or has shifted significantly from aim (is "off aim").

[0006] To control quality, a supervisor procedure should have the capability to change the operating point of the process (via the lower level controls) when a measured property goes off aim. It should have the ability to act in response to new data or statistical tests, or to act at regular time intervals. It should also be able to preemptively change the operating point when basic conditions (such as plant production rate) change. It should allow a number of independent control objectives, and new ones should be easy to add. Since the process may use any number of different low level controllers, the supervisor should be able to communicate with all of them.

[0007] To work effectively with plant operators, a supervisor procedure should be understandable. It should carry out its control actions in a way that is natural and understandable to operators. It should provide enough information

about its current state and its past actions for the operator to judge its performance. It should inform the operator when it acts (or chooses not to act), explaining how much action was taken, where it was taken, why it was done, and what effect it might have. Since the effect of actions taken to control quality and reduce cost can last longer than a single shift, it should provide a record of all its actions.

5 [0008] To act appropriately under all circumstances, to reduce operating costs in a way consistent with quality, to help avoid unnecessary upsets and shutdowns, and to take operating procedures into account, a supervisor should ideally include the logical decision making capabilities of expert systems. Because decisions will normally focus on a specific task or area, many independent expert systems should be allowed. The expert systems should have access to the many sources of process measurements, laboratory measurements, and control system parameters. They should 10 be able to reason symbolically using that information, and to make their decisions take effect through communication and control actions. To work effectively, the supervisor should be able to control its expert system functions in concert with its other functions.

15 [0009] To be supported by plant personnel, the supervisor should be easy to use. It should allow common control actions to be set up easily, with a means of customizing less common functions. It should allow control actions to be changed easily. It should have a simple means of specifying the informative messages to be generated about its actions. Its expert systems should allow process knowledge to be entered, stored, and updated in a way that plant support 20 people understand. It should provide a simple, appropriate knowledge representation which naturally includes data retrieval, symbolic reasoning, and effective means of implementing decisions in the plant. The knowledge structure should allow any authorized plant expert to enter knowledge, without restricting access to those who know computer languages or have memorized special rule structures.

25 [0010] The present invention addresses many of these concerns.

[0011] Normally supervisory control has been thought of separately from another higher level of control called optimizing control, which seeks to minimize operating cost. In some cases, the requirement to minimize variation in product properties (i.e. to improve product quality) is absolutely primary, so that cost optimization only be performed as an objective secondary to quality objectives. In this environment, use of classical optimization techniques to achieve cost optimization may not be possible. In other cases, it has been possible to integrate a balance of supervisory and optimizing control into the supervisor.

#### Modularity

30 [0012] Supervisory control systems using a modular structure are well known. For example, the Process Monitoring and Control-1000 (PMC-1000) control package marketed by Hewlett Packard is a modular control package which can function as a supervisory control system. PMC modules, called blocks, perform alarming and limiting, proportional/integral/derivative control, trending, driving an electrical output, running programs, and other functions. Each block writes one or more output values into memory. To build PMC control structures, the user creates as many blocks as needed and links them to other block output values. A new runnable system must then be generated. Once the system is running, parameters such as gain constants can be changed, but the linking of blocks is fixed. PMC runs on a base time cycle, and blocks can only be scheduled to execute at multiples of the base cycle time. Although PMC maintains a historical database, it cannot be used for control, and does not effectively store intermittently sampled data. It is believed that there is no maximum number of blocks.

35 [0013] It is believed that some earlier discussion of the significance of modularity in process control software is found in Watson, "Process Control Using Modular Package Software," IEE Conference Publications number 102 (1973).

#### Historical Process Database

40 [0014] A database of historical process data is generally described in Hale and Sellars, "Historical Data Recording for Process Computers," 77 Chem. Eng'g Progress 38 (1981).

#### Continuous Control Actions

45 [0015] In classical feedback and feedforward control, the prior art teaches that the best control results are achieved by making continuous changes to the process. In computer control, where cyclic operation forces changes to be made in discrete steps, many small, frequent steps are conventionally preferred. While in principle this gives the best possible control performance, such control actions are very difficult to visualize. In fact, it may be impossible to determine what 50 actions have been taken by what control strategies, and how long the control strategies have been making changes. This makes it very difficult to judge whether control strategies are working properly, or even if they are working at all. This method of control also runs counter to the methods used by operators, who generally make a few significant changes and wait to see the effects.

5 [0016] In feedback control, the use of a deadband is a well known way of avoiding small actions caused by a noisy measurement. (That is, if the control variable falls within a specified deadband of values surrounding the goal value, the control value will not be manipulated.) This deadband, as is well known, helps to avoid instability in control systems. Statistical process control also tends to reduce the number of feedback control actions. However, neither technique is sufficient to make all control actions understandable, since some actions will not be considered noisy.

10 15 [0017] The use of a feedforward relation among control variables is also well known among those skilled in the art of process control. That is, in some cases, whenever one variable changes (e.g. if a particular control variable is manipulated for any reason), another variable will also be manipulated according to a predetermined relationship. For example, in a distillation process, it may be desirable to immediately decrease the heat input whenever the rate of feed of the crude feed stock is decreased. In feedforward control, a deadband is normally not used.

#### Control of Multiple Manipulated Variables

20 25 [0018] In many process control applications, several manipulated variables must be jointly controlled in a single control loop (e.g. in some relation to a single measured variable). A special (and very common) case of this is seen in many situations where a single manipulated variable can normally be used, but alternate manipulated variables should be used instead if the first-choice manipulated variable becomes constrained. When human operators optimally handle problems of this kind, their choice of which output to change will often be made heuristically, based on cost, quality, response dynamics, and process stability.

30 [0019] "Decoupling" is a conventional way of reducing multi-input multi-output problems to sets of single-input single-output problems. In decoupling, it is usually assumed that all of the manipulated variables should be changed.

35 40 [0020] A different but related problem arises when a number of manipulated variables ("knobs") can be changed to respond to a single measured variable. Operators often use a heuristic approach in choosing which knob (or knobs) to manipulate, and sometimes choose not to act. The heuristic approach may consider cost, quality, response dynamics, and process stability. It may include alternate knobs to be used when all of the preferred knobs are constrained. Classic control methods are not well suited to this approach.

#### Expert Systems Generally

45 50 [0021] The term "expert system" is used in the present application (in accordance with what is believed to be the general usage at present) to refer to a system which includes non-trivial amounts of knowledge about an underlying problem. Almost any control system which has been customized for a particular application might be argued to embody small amounts of relevant knowledge in its very structure, but the term expert system is generally used only for systems which contain enough accessible information that they can usefully supplement the knowledge of at least some (but normally not all) human users who must deal with problems of the type addressed. Expert systems at their best may serve to codify the expert knowledge of one person (a "domain expert"), so that that person's expertise can be distributed and made accessible to many less expert users who must address problems of a certain type. Some well-known successful examples include a medical diagnostic program (MYCIN) and a diagnostic program which assists mechanics working on diesel engines.

55 60 [0022] As these examples show, one very common area of application for expert systems has been fault diagnosis. Many other areas of application have been recognized; see generally Expert Systems (ed. R. Forsythe 1984); P. Harmon and D. King, Expert Systems (1985); and Donald Waterman, A Guide to Expert Systems (1984).

#### Knowledge Input and Updating

65 70 [0023] One of the very general problems in the area of expert systems is how knowledge is to be gotten into an expert system in the first place. That is, specialists in artificial intelligence often assume that a "knowledge engineer" (that is, a person who is experienced and competent in the specialized computer languages and software commonly used for artificial intelligence applications) will interview a "domain expert" (that is, a person who actually has expert knowledge of the type of problems which the expert system is desired to be able to address) to extract his expertise and program an expert system accordingly. However, there are some very important drawbacks to this paradigm. First, competent "knowledge engineers" are not readily available. In particular, the requirements of maintaining a real-world application (such as an expert system for chemical process control, as in the preferred embodiments disclosed below) are such that it is dangerous to rely on a sufficient supply of "knowledge engineers" to go through the iterations necessary to not only input the knowledge base reliably, but also maintain the software base once it is created.

75 [0024] The rapidly developing art of software engineering has shown that one of the key requirements for a large software system is that it be maintainable. Thus, for example, the software system must be set up so that, after the technologist who first puts together an expert system is gone, it can be maintained, modified, and updated as necessary

by his successors.

[0025] Thus, one key problem in the area of expert systems is the problem of maintenance and updating. Especially in more complex real-world applications, it is necessary that a large software structure, such as that required for a sophisticated expert system, be maintainable. For example, in an expert control system, control strategies may be modified, new control strategies may be introduced, sensor and/or actuator types and/or locations may be changed, and the economic factors relevant to cost versus throughput versus purity tradeoffs may change. Normally, expert systems attempt to maintain some degree of maintainability by keeping the inference rules which the processor executes separate from the software structure for the processor itself. However, this normally tends to lead to a larger software structure which operates more slowly.

[0026] Specialists in expert systems also commonly assume that expert systems must be built in a symbolic processing environment, e.g. in environments using LISP or PROLOG. Even for complex processes, a single large knowledge base is usually assumed. The program which processes the knowledge therefore requires complex procedures for processing the knowledge base, and these are typically coded separately from the knowledge. This leads to large software structures which execute slowly on conventional computers. Specialized "LISP machines" are commonly recommended to speed up the inference process.

#### Expert System Knowledge Structures

[0027] Published material regarding knowledge based systems (expert systems) has proposed several classifications for the types of rules which are to be used. For example, U.S. Patent No. 4,658,370 to Erman *et al.* describes "a tool.. for building and interpreting a knowledge base having separate portions encoding control knowledge, factual knowledge, and judgmental rules." (Abstract). The method described in this patent still appears to rely on the availability of a "knowledge engineer. This patent appears to focus on the application of an expert system as a consultation driver for extracting the relevant items of knowledge from a human observer. Knowledge is separated into factual knowledge such as classes, attributes, allowed values, etc., which describe the objects in the domain; judgmental knowledge, which describes the domain (and its objects) in the form of rules; and control knowledge describing the problem solving process to be used by the inference procedure in processing the knowledge. (The control knowledge has nothing to do with control of an external process.) This knowledge structure is designed to make the task of knowledge engineering easier, and to make the knowledge system and its reasoning during a consultation easier to understand. The knowledge base is written in a specialized programming language. This is a very powerful structure, which requires a very high skill level.

[0028] Expert system development tools which are designed to make the input of knowledge easier have been developed. U.S. Patent 4,648,044 to Hardy, *et al.*, describes "a tool for building a knowledge system.. [which] includes a knowledge base in an easily understood English-like language expressing facts, rules, and meta-facts for specifying how the rules are to be applied to solve a specific problem". (Abstract).

Although this tool is not as complex as some current expert systems tools, the knowledge must be entered in a rigidly structured format. The user must learn a specialized language before he can program the knowledge base. Despite some simplification in the development process, a fairly high skill level is still required.

#### Expert Systems for Process Control

[0029] Chemical processing plants are so complex that few people develop expertise except in limited areas of the process. Plants run around the clock, production rates on a single line are very high, and startup is usually long and costly, so improper operation can be very costly. It has also been found that, in a complex chemical processing plant, some operators can achieve substantially higher efficiencies than others, and it would be advantageous if the skill level of the best operators could be made generally available. Expert systems promise significant benefits in real-time analysis and control by making scarce expertise more widely available. However, application of expert systems in this area has not progressed as far as it has in interactive, consultative uses.

[0030] Integration of expert system software with process control software poses special problems:

[0031] First, there is the problem of how the software structure for an expert system is to be combined with the software for a process control system. Several expert systems which have been suggested for process control have used an expert system as the top-level supervisor procedure for the control system.

[0032] Second, as discussed above, many process control strategies have difficulty with situations where there are multiple control parameters (inputs to the process) which could be manipulated. That is, for processes which have only one primary control parameter (as many do), the problem of what value to set for that control parameter is in significant ways a much simpler problem than the question of which one or ones of multiple control parameters should be addressed, and in which direction.

[0033] It should also be noted that the use of an expert system to design a new process (or to debug a newly intro-

duced process) has significantly different features from the problem of optimally controlling an existing process. Similarly, while expert systems have also been applied to the automatic distribution of jobs to multiple work-stations through an automated materials handling system (an example of this is the DISPATCHER Factory Control System developed by Carnegie Group Inc.), the queuing problems presented by the allocation of different types of materials in batches to many parallel assembly workstations making different products are quite different from the problems in continuously operating single line processes, particularly chemical processes.

#### "RESCU"

[0034] The system known as "RESCU" resulted from a collaborative demonstration project between British government and industry. See, e.g., Shaw, "RESCU online real-time artificial intelligence," 4 Computer-Aided Engineering J. 29 (1987); and the Digest of the IEE Colloquium on 'Real-Time Expert Systems in Process Control', held 29 November 1985 at Salford, U.K.. From available information, it appears that this is a real-time expert system which was developed to provide advice on quality control in an detergent plant. The system searches for a hypothesis about the plant which is supported by process data, and uses it as the basis for advice. This system also uses a single knowledge base for the entire plant and thus requires complex inference control methods.

#### "Falcon"

[0035] "Falcon" is a fault diagnosis system for a chemical reactor, which monitors up to 30 process measurements and seeks to identify a set of up to 25 failures in the process. This was developed as a demonstration project between DuPont, the Foxboro Company, and the University of Delaware, and is described, for example, in D. Rowan, "Using an Expert System for Fault Diagnosis," in the February 1987 issue of Control Engineering. See also "Troubleshooting Comes On Line in the CPI" in the October 13, 1986, issue of Chemical Engineering at page 14. This system required several man years of development, and because it is programmed in LISP, it has proven difficult to maintain the knowledge base through process changes.

#### "ONSPEC Superintendent"

[0036] The "ONSPEC Superintendent" (TM), marketed by Heuristics Inc., is a real-time expert systems package which monitors data from the ONSPEC (TM) control system. See Manoff, "On-Line Process Simulation Techniques in Industrial Control including Parameter Identification and Estimation Techniques," in Proceedings of the Eleventh Annual Advanced Control Conference (1985); and Manoff, "Control Software Comes to Personal Computers," at page 66 of the March 1984 issue of Control Engineering. The "Superintendent" monitors for conformance with safety and control procedures and documents exceptions. It can also notify operators, generate reports, and cause control outputs.

#### "PICON"

[0037] The PICON (TM) system, which was marketed by Lisp Machines, Inc. (LMI), was apparently primarily intended for real-time analysis of upset or emergency conditions in chemical processes. It can monitor up to 20,000 input process measurements or alarms from a distributed control system. It uses a single knowledge base (e.g. containing thousands of rules) for an entire process. To handle such a large number of rules, it runs on a LISP computer and includes complex inference control methods. PICON must be customized by a LISP programmer before the knowledge base can be entered. The domain expert then enters knowledge through a combination of graphics icons and Lisp-like rule constructions. See, for example, L. Hawkinson et al., "A Real-Time Expert System for Process Control," in Artificial Intelligence Applications in Chemistry (American Chemical Society 1986), and the R. Moore et al. article in the May 1985 issue of InTech at page 55.

#### Self-tuning Controllers

[0038] Another development which should be distinguished is work related to so-called "self-tuning controllers." Self-tuning single- and multiple-loop controllers contain real-time expert systems which analyze the performance of the controller (See "Process Controllers Don Expert Guises", in Chemical Eng'g, June 24, 1985). These expert systems adjust the tuning parameters of the controller. They affect only low-level parts of the system, and use a fixed rule base embedded in a microprocessor.

[0039] The paper 'Use of Expert Systems in Closed Loop Feedback Control' by K.E. Arzen, Proc. 1986 American Control Conference, 18 June 1986 IEEE, New York, discloses a control system for controlling a substantially continuous process having a number of sensors for sensing conditions in the process, a number of actuators for changing condi-

tions in the process, a controller for controlling the operation of the actuators in accordance with data received from the sensors and in accordance with control parameters and a process supervisor which supervises the controller by selectively defining one or more of the control parameters in dependence upon data received from the process.

[0040] The paper 'Expert Identification and Control' by S.P. Sanoff and P.E. Wellstead, Proc. 1985 IFAC Identification and System Parameter Estimation, York, UK, discloses a desired system which will assist an operator to commission and manage a self-tuner on-line. The system employs expert systems in order to simplify the task of commissioning and operating self-tuning controllers.

#### SUMMARY OF THE INVENTION

[0041] The present invention provides a computer-based method for operating a substantially continuous process, comprising the steps of: (i) operating the process with one or more sensors arranged to sense conditions in the process, and one or more actuators arranged to change conditions in the process; (ii) controlling one or more of said actuators with a process controller in accordance with signals received from one or more of said sensors and in accordance with one or more control parameters; and (iii) running a process supervisor procedure for supervising the operation of said controlling step by selectively defining one or more of said control parameters in dependence upon data received indirectly and/or directly from said process; characterised by providing a plurality of expert subprocedures, each for performing a respective different expert task relating to the process using a knowledge base and inference structure relevant to the process, and for outputting expert advice data; and in that said process supervisor procedure runs independently of said controlling step and uses a plurality of substantially self-contained software modules, each module defining a procedure for performing a desired task, and wherein said process supervisor procedure is arranged to call, under predefined conditions, said expert subprocedures which output said expert advice data for use by said supervisor procedure in selectively defining said one or more control parameters.

[0042] The present invention also provides a computer-based apparatus for controlling a substantially continuous process, comprising: (a) one or more sensors for sensing conditions in the process, and one or more actuators for changing conditions in the process; (b) a process controller for controlling one or more of said actuators in accordance with sense data generated by at least one of said sensors and in accordance with respective control parameters; and (c) process supervisor means arranged to receive data indirectly and/or directly from said process and operable for supervising the operation of said process controller by selectively defining one or more of said control parameters in dependence upon said received data; characterised in that a plurality of expert subprocedure means are provided, each for performing a respective different expert task relating to the process using a knowledge base and inference structure relevant to the process and for outputting expert advice data; and in that said process supervisor means is operable independently of said process controller and comprises: (i) a plurality of substantially self-contained software modules, each module defining a procedure for performing a desired task; and (ii) means for calling, under predefined conditions, at least one of said plurality of expert systems which outputs said expert advice data for use by said process supervisor means in selectively defining said one or more control parameters.

[0043] In this section various features of the embodiments described in the present application will now be discussed, and some of their respective advantages described. Of course, not all of the discussions in this section define necessary features of the invention for at least the following reasons: 1) various parts of the following discussion will relate to some (but not all) classes of novel embodiments disclosed; 2) various parts of the following discussion will relate to innovative teachings disclosed but not claimed in this specific application as filed; 3) various parts of the following discussion will relate specifically to the "best mode contemplated by the inventor of carrying out his invention" and will therefore discuss features which are particularly related to this subclass of embodiments, and are not necessary parts of the claimed invention; and 4) the following discussion is generally quite heuristic, and therefore focusses on particular points without explicitly distinguishing between the features and advantages of particular subclasses of embodiments and those inherent in the invention generally.

[0044] Various classes of embodiments described herein provide a process control system, wherein a process which operates substantially continuously is controlled by a system which includes (in addition to a process control system which is closely coupled to the underlying process and which operates fairly close to real time, i.e. which has a maximum response time less than the minimum response time which would normally be necessary to stably control the underlying process) at least some of the following features:

- 1) A supervisor procedure, which has a modular structure, and retrieves process measurements from the process control system (or other process data collection systems), passes control parameters to the process control system, and communicates with people. Preferably, the supervisor includes the capability for statistical process control. The supervisor preferably runs on a computer system separate from the process control system.
- 2) The supervisor procedure can preferably call on one or more expert system procedures as subroutines. This is particularly useful in control applications where there are multiple possible manipulated variables, since the expert

system(s) can specify which manipulated variable (or variables) is to be adjusted to achieve the end result change desired, and the supervisor system can then address simpler one-dimensional control problems.

5 3) Preferably, at least some users can call on a build-supervisor procedure which permits them to define or redefine modules of the supervisor procedure by editing highly constrained templates. The templates use a standardized data interface (as seen by the user), which facilitates the use in control actions of data from a wide variety of systems. The templates in the available template set preferably contains highly constrained portions (which are optimized for the most common functions), and pointers to functions which can be customized by the user.

10 4) Preferably, the build-supervisor user can also call on a build-user program procedure, which allows fully customized control functions to be programmed by sophisticated users. The build-user program procedure can also be used to create customized message generation functions. These can be used to generate messages describing the actions of the supervisor, and also to call other sub-procedures, such as the expert procedures.

15 5) Preferably at least some users are also permitted to call on a build-expert procedure which can be used to construct an expert system. Knowledge is specified by user input to a set of highly constrained, substantially natural language templates. The templates use a standardized data interface (as seen by the user), which facilitates the use in the expert system of data from a wide variety of systems. The completed templates can then be compiled to produce a runnable expert system. Preferably, the user can also retrieve, examine, and modify the input from previously specified templates. Thus, an expert system can be modified by recalling the templates which specified the current expert system, modifying them, and recompiling to generate a new runnable expert.

20 6) A historical process database advantageously standardizes the access to current and historical process data by the supervisor and expert procedures. This is particularly useful for collecting the results of laboratory characterizations over time of the underlying process.

#### Control of Continuous Processes

25 [0045] The goals in management of a substantially continuous process include the following:

1) Maximizing quality: In the chemical process industry, it is important to reduce variation in measured properties of the product, and to control the average measured properties at specified aim values.

30 2) Minimization of cost of manufacture: The process must be operated in a way that efficiently uses energy and feedstocks without compromising quality objectives. Upsets and inadvertent process shutdowns, which adversely affect quality and production rate, and reduce the total utility (fractional uptime) of the plant, are all costly and must be avoided.

#### Control of Multiple Manipulated Variables

35 [0046] As noted above, in many process control applications, several manipulated variables must be jointly controlled in a single control loop (e.g. in some relation to a single measured variable). A special (and very common) case of this is seen in many situations where a single manipulated variable can normally be used, but alternate manipulated variables should be used instead if the first-choice manipulated variable becomes constrained. When human operators optimally handle problems of this kind, their choice of which output to change will often be made heuristically, based on cost, quality, response dynamics, and process stability.

40 [0047] One novel approach to this problem (which is used in several of the preferred embodiments below) is to decompose the multiple-variable problem into a set of single-variable problems. An expert procedure is used to decide which control parameter(s) to adjust, and one or more from a set of single-input single-output procedures are used to make the adjustment(s). Not only does this facilitate quality, cost, and plant operability objectives, but it results in control strategies which act properly over a much wider range of conditions. Correct actions are taken, where conventional control methods would make no action or wrong actions. This improves the usefulness of the control strategy to the operator, and leads to higher use of the controls.

45 [0048] The various novel ideas described below are particularly advantageous in such multiple control parameter problems. In the presently preferred embodiment discussed below, a dimethyl terephthalate process (DMT) process is presented as an actual example to show the advantages achieved by the various novel ideas disclosed in this context.

#### Discrete Control Actions

50 [0049] As mentioned above, control systems that continuously change manipulated parameters are very difficult to monitor. Since operators depend on the supervisor procedure to maintain important product properties and process operating conditions, it is important that they be able to understand and judge supervisor performance. By restricting supervisor changes to a reasonably small number of significant discrete actions, supervisor performance becomes

much more understandable.

[0050] One novel teaching stated in the present application is an integrated system for process control in which a process supervisor procedure (which is preferably the top level procedure) defines parameters for one or more control systems (or control procedures). The supervisor procedure changes control parameters only in discrete actions, and the thresholds for the decision to act are preferably made large enough (for each control parameter) that every action must be a significant change.

[0051] A related novel teaching herein is that every control action taken by the supervisor should be reported out to plant personnel in a substantially natural language message. Preferably, instances where action would be desirable but is not possible (because of constraints or other unusual circumstances) should also be reported. Preferably, a cumulative record of the messages is kept, and is available for review by operators and plant support people. Preferably, the message should report the time, amount, location, and reason for each action. Other relevant information, such as the time stamp of relevant sampled data, and the nature of statistical deviations from aim should preferably be included as well. Since every action is significant, and the number of actions is reduced, the cumulative record provides a meaningful record of supervisor performance.

[0052] This is particularly advantageous for systems where some of the relevant time constants are so slow that dynamic process responses last several hours (or longer). A new operator coming on duty at a shift change can use the cumulative record to judge what effects to expect from supervisor actions on the previous shift.

[0053] The use of a deadband in feedforward action is one novel means that is advantageously used to discretize supervisor actions. Feedforward action is taken only when the measured value changes by more than the deadband from its value at the last action. This generates a series of discrete changes in the manipulated variable, which can be effectively logged and evaluated by operators.

[0054] Statistical filtering of discretely measured values also serves to reduce control actions to a few significant changes. Statistical tests, as is well known, distinguish normal variation around the average from significant deviations from the average. In most cases, a number of measurements will be needed to indicate a deviation. By only acting on statistical deviations, relatively few, but significant, actions will result.

#### Expert Systems for Process Control

[0055] A general problem with expert systems is how the expert system software is to be integrated with process control software. Several expert systems which have been suggested for process control have used an expert system as the top-level supervisor procedure for the control system. However, several of the novel embodiments disclosed herein achieve substantial advantages by departing from this conventional structure. For one thing, if the expert system is the top level procedure, then it becomes more difficult to accommodate more than one expert in the system (or, to put this another way, the potential modularity of the expert system cannot be fully exploited). Thus, one significant advantage of several of the novel embodiments disclosed here is that use of more than one expert system within a single integrated system becomes much more advantageous.

#### Types of Process Control Systems

[0056] It should also be noted that the use of an expert system to design a new process (or to debug a newly introduced process) has significantly different features from the problem of optimally controlling an existing process. While various ones of the novel ideas disclosed herein may have significant applications to such problems as well, the presently preferred embodiment is especially directed to the problem of optimally controlling an existing operating process, and the various novel ideas disclosed herein have particular advantages in this context.

[0057] A significant realization underlying several of the embodiments disclosed in the present application is that the structure of expert systems for process control applications can advantageously be significantly different from that of other expert system problems (such as consultative expert systems problems, in which a human is queried for information). The Hardy *et al.* and Erman *et al.* patents illustrate this difference.

Consultative expert systems seek to substantiate one of a number of possible causes by interactively querying the user about the symptoms. Such systems must use complex knowledge representations and inference methods to minimize the number of user queries by carefully selecting the information they solicit. Moreover, since the user is not an expert, the system should be able to explain why it is requesting information.

[0058] In contrast, the real-time process problem is much simpler. The information needed by the expert is typically in the form of process measurements, which can be rapidly retrieved from process control and data systems without human intervention. There is much less need to minimize the requests for information. In fact, it may be faster to retrieve all the data that could be relevant to the problem than to determine what data is relevant. Moreover, since the experts will run automatically, there is no need to explain the reasoning during the inference process. As long as the rulebase is not too large, the process control expert can operate effectively using a simple "forward chaining" (or data driven)

inference method. There is no need for the complex "backward chaining" procedures used in the consultative systems. Moreover, if a number of modular expert subprocedures are used within a single process, each expert tends to be smaller, and is more likely to work effectively in forward chaining mode. The presently preferred embodiment is especially directed to process control and monitoring, and the novel ideas disclosed herein have particular advantages in this context. However, various ones of the novel ideas may have significant applications to other problems as well.

[0059] It is believed to be a significant idea to use expert system techniques to point to the direction of action in a multi-parameter control problem, as discussed above. One advantage is that the use of the expert permits more cases to be handled; for example, when one control parameter is up against its limits, the expert system can specify another parameter to be changed. The expert can also be especially advantageous in preventing a wrong action from being taken: in some types of processes it is conceivable that erroneous control strategies could potentially cause property damage or injuries, and the natural language inference rules of the expert (possibly combined with a more quantitative optimization scheme) can usefully ensure that this cannot happen. Thus, one advantage of various of the process control expert system embodiments disclosed in the present application is that they facilitate reliable implementation of a control strategy which (primarily) prevents a clearly wrong action from being taken, and (secondarily) permits minimizing costs. In particular, it is especially advantageous to use a knowledge based structure where the rules are constrained to be of the three types described in the context of a process control application. The retrieval rules permit the predominantly quantitative sensor data (and other input data) to be translated into a format which is suitable for expert system application, and the control rules provide a translation back from expert system reasoning into an output which matches the constraints of the control problem.

[0060] The present invention is particularly advantageous in controlling processes which are substantially continuous, as distinguished from job shop processes. That is, while some computer-integrated manufacturing systems focus primarily on issues of queuing, throughput, statistical sampling of workpieces for inspection, etc., substantially continuous processes (such as bulk chemical synthesis and/or refining processes) typically demand more attention to issues of controlling continuous flows.

#### Expert Systems Generally

[0061] The present application contains many teachings which solve specific problems and offer corresponding advantages in the sub-class of expert systems used for process control, or even the sub-sub-class of expert systems used for control of substantially continuous processes. However, the present application also discloses many novel features which could be adopted into many other types of expert systems, and/or into many other types of control applications, while still retaining many (if not all) of the advantages obtained in the context of the presently contemplated best mode.

[0062] Similarly, while the present application describes numerous novel features which are particularly applicable to rule-based forward-chaining expert systems, some of the ideas described herein are believed to be very broadly novel, and could be adapted for use with other types of expert systems too.

#### Natural-Language Rule Statements

[0063] One of the novel teachings in the present application provides an expert system tool in which knowledge is entered into the knowledge base through a limited set of pre-defined, highly constrained, natural-language knowledge structures which are presented as templates. In typical previous expert systems, knowledge is coded in the strict syntactical format of a rule or computer language, which allows great flexibility in knowledge representation. The person entering the knowledge (hereafter referred to as the developer) must learn the syntax, must choose an appropriate knowledge representations, and must formulate syntactically correct input.

[0064] In contrast, by restricting the developer to constrained, pre-defined structures, the need to learn rule or language syntax and structure is eliminated. Moreover, if the number of such pre-defined knowledge structures is small enough, the total knowledge representation in the expert system can be easily understood. Thus, a knowledge engineer is not needed. The domain expert can enter the knowledge to build an expert system directly. The developer's input can then be translated automatically into an operational expert system. The developer need not be concerned with or aware of the specific language or system used to implement the expert.

[0065] Another novel teaching is that the knowledge entered into the pre-defined natural-language structures is stored in substantially natural-language form. This permits the knowledge to be revised at any time in the form in which it was originally entered: the developer simply recalls the stored template information, modifies it, and stores the modified knowledge. This is also simple enough to be done by the domain expert. The modified knowledge can then be automatically translated into a modified operational expert.

[0066] Another significant advantage of several of the disclosed novel embodiments for creating an expert system is that the expert can be significantly more compact and faster in execution. This is achieved by integrating the expert

system's rules with the code which performs the inference function. This allows many independent runnable expert systems to be created. Moreover, the ease and simplicity of knowledge updating can still be preserved by maintaining the natural language form of the knowledge. The knowledge base can easily be reviewed and modified without hindrance from the specific inference method used in the runnable system.

5 [0067] Another novel feature of several of the disclosed embodiments is the use of a standardized data interface (as seen by the user) in the knowledge templates, which facilitates the use in the knowledge base of data from a wide variety of systems. Expert systems are allowed to require data from process or laboratory measurements (both current and historical), or data collected from other sources (such as on-line analyzers), or data and parameters from the process control systems. A standard interface to all such data sources facilitates use of the data in expert systems, 10 since domain experts usually lack the programming expertise that would otherwise be needed to access these data sources.

#### Expert System Rule Types

15 [0068] As mentioned above, previous expert systems tools normally use a rule or computer language which allows great flexibility in knowledge representation. One novel teaching in the present application is the restriction of the knowledge structure within an expert system to rules of three highly constrained types. The three rule types are: 1) retrieval rules, which each assign one of several descriptors to a name in accordance with the values of numeric inputs; 2) analysis rules, which each can assign a descriptor to a name in accordance with the descriptor/name assignments 20 made by other rules; and 3) action rules, which either execute or don't execute a command in accordance with the descriptor/name assignments made by other rules.

[0069] Preferably only the retrieval rules include numeric operations. Preferably only the action rules can enable execution of an external command (*i.e.* a command which does not merely affect the operation of the expert procedure). Preferably each of the action rules requires only a logical test for the assignment of a descriptor to a name. 25 Preferably none of the action rules can assign a descriptor to a name.

[0070] While this organization of an expert system's structure is especially advantageous in the context of a process control expert system, it can also be applied to other types of expert systems. In a process control system, the relevant inputs will normally be process data, laboratory data, or control system parameters. The relevant outputs will normally be executable procedures which affect the operation of control or supervisor systems, or communicate with operators 30 or domain experts. This teaching could also be applied to expert systems generally, in which other input and output functions are more important.

[0071] For example, in consultative use, retrieval rules need not be confined to numeric inputs, but could accept the natural language descriptor/name assignments as input from the user. To better control the requests for input, such consultative retrieval rules could advantageously execute contingent upon a test for the previous assignment of a 35 descriptor to a name.

[0072] In general, this structuring of the inference rules provides for a more understandable expert. The retrieval rules provide access to process and control system data, and translate from quantitative input data into a natural language form. The emulation of natural-language reasoning is concentrated as much as possible in the analysis rules, which capture knowledge in a form which might be used to communicate between domain experts. The action rules 40 translate from the natural language inference process back to output procedures which are meaningful in the computer and control system being used.

#### Modular Organization

45 [0073] The organization preferably used for process control has substantial advantages. The top level procedure is a modular process supervisory controller. The supervisor modules allow flexible specification of timing and coordination with other modules. Modules carry out commonly used control functions, using data specified through a standard data interface, as well as calling user customized functions. User customized functions might generate messages, perform unusual control actions, or call expert system procedures. Using the build-supervisor procedure, users can define or 50 redefine modules by editing highly constrained templates which include a standard data interface specification. The standardized data interface (as seen by the user) facilitates communications with an extremely wide variety of systems. Dynamic revision is achieved by storing the user input to the constrained templates as data in a storage area accessible to both the supervisor and build-supervisor procedures. The running supervisor examines the stored data to determine which functions have been specified for that module, and what data sources have been specified through the standard 55 data interface. The supervisor then calls an appropriate modular function and passes the user-specified data.

[0074] This organization is especially advantageous in providing parallelism and branching in control strategies. That is, the modular organization of the presently preferred embodiment permits at least the following capabilities:

5 a) control strategies for more than one independent control application can be defined and updated;  
 b) control strategies for more than one lower level process control system can be defined and updated;  
 c) alternative control strategies can be defined and stored, so that an expert system (or other software or user command) can switch or select between control strategies merely by selecting or "de-selecting" modules;  
 d) timing and coordination of module functions is facilitated;  
 e) multiple independent expert system procedures can be utilized within a single supervisor;  
 f) more than one user can define control strategies by accessing different modules, simultaneously if desired.

10 [0075] Another novel teaching herein is that each supervisor module (or, less preferably, less than all of the module types) should preferably contain a pointer to optional user-customized functions. These functions can be used to generate informative messages about module actions, or a sophisticated user can implement unusual or non-standard control functions, or other customization utilities (such as the build-expert procedure in the presently preferred embodiment) can be used to generate functions accessed in this manner.

15 [0076] This structure is "modular" in the sense that users can call up and modify the various blocks separately; but, as will be discussed below, the command procedures which perform the standardized block functions are not necessarily separate within the source code. That is, modularity is advantageously achieved by storing the template-constrained user inputs to each block as data; when the user wishes to modify the block, the data is translated back into corresponding fields in the template.

20 [0077] Preferably, one of the modular functions in the supervisor is statistical filtering. This is particularly useful in that statistical filtering can be introduced wherever it is advantageous, without requiring extensive custom programming by the users. As described above, statistical filtering is advantageous both for avoiding overreaction to insignificant changes, and also for aiding the understanding by plant operators by reducing the number of actions.

25 [0078] One of the novel teachings contained in the present application is that the use of statistical filtering helps to minimize the number of control parameter adjustments performed by the expert system, which in turn is very advantageous (as discussed below) in providing an understandable log of control actions taken.

#### Sequencing Modular Blocks

30 [0079] One novel teaching herein is a system for process control having a modular supervisor procedure which includes novel module timing and sequencing methods. Users can preferably specify modules by editing highly constrained templates, which include several specifiers for methods to be used in controlling and coordinating module execution. Preferably the module timing options include: 1) execute module function at fixed time intervals; 2) execute module function when new data becomes available for a specified data source; 3) execute module function whenever another module executes; 4) execute module function only on programmatic request; and combinations of these. Preferably a standardized data interface is used to specify the data source for the second of these options.

#### Integration of Expert Procedures

40 [0080] The integration of expert systems into process control has been a challenging problem. Most previous attempts to use expert systems in process control have used LISP based expert systems running on a dedicated machine, often a symbolic processing machine. Usually only one expert system with a single large knowledge base is created for a process. Since the knowledge base could contain many rules, a complex knowledge representation and inference process are needed to make inferences fast enough for real-time use. The expert system typically runs independently, scheduling its own activities, and thus is effectively the "top level" procedure. Using a top level expert makes it more difficult to accommodate more than one expert system. (Another way to regard this area of advantage is to note that, without the teachings contained in the present application, the potential modularity of the expert system cannot be fully exploited.)

45 [0081] Several of the novel embodiments described herein achieve substantial advantages by using more than one expert system subprocedure within a single integrated system. Since expert decisions will normally focus on a specific task or area, the modularity of the problems can be exploited in the structure of the expert system. Also, if the experts run under control of the supervisor, it is much easier to coordinate the decisions of the expert systems with the control actions of the supervisor. Since many important uses of expert systems will affect control actions, this is an important factor.

50 [0082] Another advantage of a modular structure, where expert systems are included as independent procedures called by the supervisor, is that the overall process control system is more reliable. A badly or incompletely functioning expert system within an overall supervisor system will affect only the functions it specifically interacts with. However, the failure of a top level expert system, which controls timing and execution of control functions, could disable all supervisor functions. The modular structure also has significant advantages in maintenance and debugging.

5 [0083] Thus, the organization preferably used for process control has substantial advantages. The top level procedure is a cycling procedure which functions as a process control supervisor. The supervisor process can call on one or more expert system procedures, and the user can call on a build-expert procedure which can reconfigure one of the expert systems already present, or create a new expert system. The supervisor procedure can preferably also call on a historical data base.

10 [0084] The modular organization described is especially advantageous, as discussed above, in providing parallelism and branching in control strategies. This is especially advantageous in process control situations, since the appropriate strategies for different circumstances can be fully pre-defined by the user, and he can rapidly switch between pre-defined strategies as the need arises.

10 Historical Process Database

15 [0085] The use of a historical database of process data in combination with a process supervisor procedure and/or expert system procedure is particularly advantageous. In the presently preferred embodiment, a historical database is used which can provide a time-stamp with each piece of output data, to clearly indicate provenance, and can retrieve the stored data (for a given parameter) which bears the time-stamp closest to a given time. The historical database can preferably maintain a record of continuously measured process data (such as temperature, pressure, flow rate), as well as discretely sampled, time-delayed measurements, such as laboratory measurements. The database greatly facilitates the use of laboratory (or other sampled type) measurements. Because of the time delay in making laboratory 20 measurements, the value of the measurement when it becomes available in the database will correspond to the continuously measured data for the instant at which the measurement sample was actually taken, which might be several hours in the past. The historical database allows time delayed measurements and their corresponding continuous measurements to be used together. This is advantageous for balancing component material flows in the process. In the presently preferred embodiment, the historical process database may be thought of as providing a way to "buffer" 25 time-stamped data and provide a standardized data interface, but it also permits other functions to be served.

30 [0086] The historical database also advantageously provides a basis for statistical tests. Some statistical tests will require a number of past measurements, which can be retrieved from the database. The database also advantageously allows the calculation of time average values of measurements. This can be useful in dampening noisy signals for use in a control action. In general, the database advantageously serves to buffer data input from a number of sources, standardizing access from the supervisor and expert procedures.

35 [0087] One of the novel teachings in the present application is an integrated system for process control in which a process supervisor procedure (which is preferably the top-level procedure) is configured as a modular software structure, with modules which can be revised by a user at any time, without significantly interrupting the operation of the process supervisor. The supervisor can define control parameters for many process control procedures, and can retrieve data from many sources (preferably including a historical database of process data, which can provide time-stamped data). The supervisor can also call on various expert subprocedures. Preferably the expert subprocedures can also be modified by an authorized user at any time, by calling up and editing a set of natural-language rule templates which correspond to the rules being executed by the expert subprocedure.

40 [0088] One of the novel teachings in the present application is an integrated system for process control in which the user can customize the process supervisor procedure with reference to a standardized data interface. The data values to be used by the supervisor are specified in the standard interface by two identifiers. The first identifies which (software) system and type of value is desired. The value of a setpoint in a particular distributed control system, the value of a sensor measurement in a particular process monitoring system, the value of a constraint from a process control or supervisor system, and time averages of sensor measurements from a particular historical database are examples of 45 this. The second identifier specifies which one of that type of value is desired, for example the loop number in the distributed control system.

50 [0089] Data values specified through the standard interface may be used as measured values, manipulated values, or as switch status values indicating an on/off status. Preferably the interface allows the user to specify data in any of the relevant process control and data collection systems used for the process, or for related processes. Preferably, the interface also allows specification of data (both current and historical) in a historical process database. Since multiple control systems (or even multiple historical databases) may be relevant to the process, the standard interface greatly facilitates the use of relevant data from a wide variety of sources.

55 BRIEF DESCRIPTION OF THE DRAWING

[0090] The present invention will be described with reference to the accompanying drawings, wherein:

[0091] Figure 1 schematically shows the structure of hardware and procedures preferably used to embody the novel process control system with expert system capabilities provided by various of the innovative features contained in the

present application.

[0092] Figure 2 is a schematic representation of the flow of information in the expert system structure preferably used.

[0093] Figure 3 shows the template used for a retrieval rule in the presently referred embodiment, together with a sample of a retrieval rule which has been entered into the template.

[0094] Figure 4 shows an example of a different kind of retrieval rule, known as a calculation rule.

[0095] Figure 5 shows an example of an analysis rule 220.

[0096] Figure 6 shows the presently preferred embodiment of the template for action rules, and an example of one action rule which has been stated in this format.

[0097] Figure 7 shows an example of a chemical synthesis processing layout in which the method taught by the present invention has been successfully demonstrated. Figure 8 schematically shows the structure preferably used for the supervisor procedure 130 and the build-supervisor procedure 810.

[0098] Figure 9 shows a menu which, in the presently preferred embodiment, is presented to the user by the build-supervisor procedure 810 to select a template to provide user inputs to define or modify a block within the supervisor procedure.

[0099] Figures 10-13 show specific templates which, in the presently preferred embodiment, are presented to the user by the build-supervisor procedure to provide input to define or modify a feedback, feedforward, statistical filtering, or program block, respectively.

[0100] Figure 14 shows a block-editing utility menu presented to the user, in the presently preferred embodiment, by the build-supervisor procedure.

[0101] Figure 15 shows a flow chart for the base cycle procedure used in the supervisor procedure in the presently preferred embodiment.

[0102] Figure 16 shows a menu which, in the presently preferred embodiment, is the top-level menu presented to the user by the build-supervisor procedure, and Figure 17 shows a menu which is the top-level menu within the build-expert procedure.

[0103] Figure 18 is another schematic representation of the interrelations among the various procedures which permit user customization of functionality.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

##### 30 General Organization of Hardware and Procedures

[0104] Figure 1 schematically shows the structure of hardware and procedures preferably used to embody the novel process control system (with expert system capabilities) provided by various of the novel features described in the present application. An underlying process (for example a chemical process) is very schematically represented as a single pipe 160, on which sensors 156 and one actuator 158 are explicitly shown. Of course, real world examples are substantially more complex; Figure 7 shows the chemical process flow of a sample system in which the presently preferred embodiment has been successfully demonstrated. The various actuators 158 are controlled, in accordance with feedback signals received from various sensors 156, by one or more controllers 154.

[0105] In the presently preferred embodiment, the controller 154 is configured as a pneumatic proportional, integral, derivative (PID) controller. However, a wide variety of other controller technologies and configurations could be used. Pneumatic controllers are used in this example because they are common in the chemical process industry, and match well with the feedback requirements of chemical process control. Alternatively, an all-electronic distributed control system could be used instead. Moreover, the controller functionality could be different, *e.g.* a proportional/integral controller or a proportional controller could be used instead. In the presently preferred embodiment, the PID controller 154 is directly controlled by a computer control system 152. (This system 152 is referred to, in the various examples of user menus shown, as "PCS" (process control system.) The computer controller system 152 and the PID controller 154 may be regarded together as a single first level controller 150, and could easily be configured in that fashion (as with a distributed digital control system) to implement the present invention.

[0106] The control system 150 receives at least some of its parameters 132 (*e.g.* setpoints or feedforward ratios) from a supervisor procedure 130, which is preferably a higher level of control software. (In many of the sample user menus and forms shown, the supervisor procedure 130 is referred to briefly as "ACS.") The supervisor not only receives inputs 157 indirectly (or directly) from various sensors 156, it also receives lab measurement data 162, and also can issue calls to and receive inputs from the expert system 120, as will be described below.

[0107] In the presently preferred embodiment, the supervisor and build-supervisor procedures run on a minicomputer (*e.g.* a VAX 11/785), while the computer control system 152 is a PDP-11.

[0108] The supervisor 130 is preferably also connected to a historical process data base 140, which directly or indirectly receives the inputs from the sensors 157 and the off-line lab measurements 162. Thus, when the supervisor needs to access a value 157 or 162, it is not necessary for it to call on a physical device or read a real-time signal. It

can simply call a stored value (together with a time stamp) from the database 140. However, many of the advantages of the present invention could also be obtained without using the historical process data base 140.

[0109] In addition, the supervisor 130 preferably also embodies a statistical control system. Statistical control systems, as are well known in the art of chemical processes, are advantageous when the process characteristics and measurement characteristics are subject to significant random variation, as they normally are in the chemical process industry. Statistical filtering tests are preferably performed to filter out statistically normal variation, and ascertain whether a process has significantly deviated from its current goal or average. (Alternatively, the statistical filtering functions could be performed elsewhere in software, e.g. in the database software.)

[0110] The supervisor procedure 130 is preferably run as a cycling process, and can call multiple expert systems 120 when indicated. (In many of the sample user menus and forms shown, the expert and build-expert procedures are referred to briefly as "PACE.")

[0111] A sample realistic process context (in which numerous novel features have been successfully demonstrated) will first be described. The operation of the historical process database will next be described, since that provides a standardized data interface to which many of the other functions connect. Next, the functioning of the build-supervisor procedure will be described in detail, since that provides many details of how the supervisor is configured in the presently preferred embodiment, and after that the organization of the supervisor procedure itself will be discussed in greater detail. In later sections, the structure of the expert systems preferably used will be described in detail, and the operation of the build-expert procedure which constructs the expert systems will also be described in detail.

## 20 Sample Process Context

[0112] Figure 7 schematically shows a sample embodiment of a chemical process incorporating several novel features described in the present application. The system shown is one in which various novel aspects set forth in the present application have been advantageously demonstrated.

[0113] It should be understood that the present invention provides a tool of very broad applicability, which can be used in many processes very different from that of Figure 7. Thus, for example, various of the claims herein may refer to sensors which sense "conditions" in a process, or to actuators which change "conditions" in a process, without reference to whether one sensor or many sensors is used, whether one or several parameters is sensed by respective ones of the sensors, whether the actuators are valves, motors, or other kinds of devices, etc.

[0114] Figure 7 shows part of the distillation train of a process in which paraxylene is air oxidized to make terephthalic acid, which is then esterified with methanol and refined to dimethyl terephthalate (DMT). DMT is sold as a bulk product, and commonly used as a polyester precursor. The esterification process will produce a significant fraction of the impurity methyl formyl benzoate (MFB). One of the key objectives in a DMT synthesis process is controlling the compositional fraction of MFB, since it affects the properties of products made from DMT. The refining train shown in Figure 7 will reduce the average MFB fraction to a fairly constant level which is (in this example) about 22 ppm (by weight).

[0115] The crude feed 702 will typically have a composition which is (by weight) about 74% DMT, about 20% orthoxylene (and related components which tend to recycle with the orthoxylene), about 5% methyl hydrogen terephthalate (MHT), and about 0.2% of methyl formyl benzoate (MFB). The MFB-depleted product 740 is preferably further refined to reduce the MHT fraction.

[0116] The crude feed 702 is fed into approximately the middle of a first distillation column 710. The column 710 is heated at its base by a steam reboiler 712. The steam flow is controlled by a flow controller 714 (which is connected to an actuator 716 and a sensor 718.) Similarly, the feed flow controller 704 is connected to an actuator 706, and a sensor 708. The column 710, as operated in the presently preferred embodiment, has internal pressures and temperatures which range from about 230 Torr at about 230° C at its bottom to about 55 Torr at about 70° C at its top. The vapor stream 720 is passed through a condenser 722, and some of the resulting condensate is fed back into the column as reflux 724. The product stream 726 has a mass flow rate of about 20% of the crude feed 702, and is recycled. A bottom product 728 is fed to the top of a second distillation column 730. The second distillation column has a steam reboiler 732 near its bottom (controlled by a steam flow controller 734, actuator 736, and sensor 738). The pressures and temperatures in the second column 730 (which in the user screens of the presently preferred embodiment is frequently referred to as the "MFB column") range from about 240° C at about 235 Torr at the bottom of the column to about 70 Torr and about 190° C at the top of the column. The bottom product 740 of the column 730 (which has a mass flow of about 0.8 of the crude feed 702) is the MFB-purified product. (In this product the fraction of MFB will on average have been reduced to about 22 ppm, for the conditions given.) The top product 742 of the column 730 is passed through a condenser 744 and reintroduced into column 710 as a bottom feed. (Column 710 is referred to, in the specific example given below, as the "xylene column".) The mass flow in the loop 728/742 is quite large; typically the mass flow of flow 728 will be about three times the mass flow of the crude feed 702.

[0117] In addition, a third distillation column, in the presently preferred embodiment, is operated in parallel with a middle section of column 710. This third column 750 is fed a side draw stream 752 from the first column 710. The vapor

stream 754 of column 750 is passed through a condenser, and part of the condensate is reintroduced to column 750 as a reflux 758. Most of the remaining condensate is reintroduced to first column 710 as an upper middle feed. Similarly, the liquid stream 762 of third column 750 is partly reintroduced as a bottom feed after being vaporized in the reboiler 764, but is also partly fed back into column 710 as a lower middle feed 766. The additional separation provided by the third column 750 enhances the net compositional segregation of MFB. The middle product 768 of the third column 750 is a low-flowrate product flow (typically 0.003 times the mass flow of the crude feed 702), and this product flow removes most of the undesired MFB impurity from the system. The temperatures and pressures in the third column 750 range from (in this example) about 230° C at about 260 Torr at the bottom of the column to about 60 Torr at about 125° C at the top of the column. Stream 761 is a small purge stream removing intermediate materials.

[0118] In the sample embodiment, the three primary control points for control of MFB composition are the steam feed to the MFB column reboiler 730, which is controlled by flow controller 734; the steam feed to the xylene column reboiler 710, which is controlled by flow controller 714; and the feed of crude feed stock to the xylene column 710, which is controlled by flow controller 704. Numerous other controllers, pumps, and other process equipment maintain the temperatures, pressures, and flow rates at other points in the process. In accordance with principles well known in the art of chemical engineering, this serves to maintain mass and energy balances and compositional trends consistent with the ultimate control objective, which is to maintain a high and constant purity in the product stream 740.

#### Historical Process Database

[0119] In the presently preferred embodiment (as shown in Figure 1), the supervisor 130 receives data primarily through a historical process data base 140, which directly or indirectly receives the inputs from sensors 157 and off-line laboratory measurements 162. Thus, when the supervisor needs to access a value 157 or 162, it is not necessary for it to call on a physical device or read a real-time signal, since it can simply call a stored value (together with a time stamp) from the database 140.

[0120] In the preferred embodiment, every data value provided by the historical database has a timestamp attached. Data are received in at least two ways: first, some parameters are received as nearly continuous data flows (more precisely, as high-sampling-rate time series). For example, the data 157 from sensors 156 (e.g. temperature sensors) will be received as a series of digital values from analog-to-digital converters 155. In the presently preferred embodiment, compression algorithms are used to reduce the storage requirements of this data, and permit a usefully long period of time to be represented without requiring impractical amounts of storage space. However, this operation (which includes both compression and decompression algorithms) is essentially invisible to the supervisor procedure 130.

[0121] Secondly, lab analysis data 162 can also be stored in the historical database 140. For example, compositional measurements must normally be done off-line. A physical sample will be pulled from the physical process flow and sent to the laboratory for analysis. The resulting lab analysis value is entered into the historical database, timestamped with the time the sample was taken.

[0122] A third source of data is simulations 143: running processes can be simulated, using any of a variety of currently available simulation methods, and predicted conditions can be stored in the historical database (together with the proper timestamp). Thus, for example, control strategies can access data generated by complex real-time simulations.

[0123] Thus, many of the advantages of the database 140 derive from the fact that it can provide a timestamp to accompany every piece of data it provides. In addition, in the presently preferred embodiment, the database also stores the name and units for each parameter. As presently practiced, the database is also able to perform a variety of other functions, including monitoring, activating alarms if certain sensed measurements reach certain critical levels, output processing (i.e. loading data out to physical devices), generating plots of selected parameters over time, as well as other common database functions (e.g. generating reports).

[0124] This structure is quite flexible: for example, in alternative embodiments, one supervisor procedure could interface to multiple databases 140, and/or one database 140 could receive calls from more than one supervisor procedure 130 (which optionally could be running on different systems).

#### Supervisor and Build-Supervisor Procedures

[0125] The present application describes some very advantageous features of novelty in the supervisor procedure 130 and build-supervisor procedure 810, which could optionally and less preferably be incorporated in embodiments which did not include at least some of the features described in the context of the expert and build-expert systems 110 and 120.

[0126] The supervisor procedure 130 preferably used contains a modular software structure which greatly facilitates initial setup and also modification. Preferably the supervisor procedure 130 is a cycling procedure constructed as a set of blocks. That is, each block defines a core procedure which (as seen by the user, both initially and whenever

called up for modification) is substantially self-contained, and which (in the presently preferred embodiment) is of one of four types. Preferably each block is either a feedforward block, a feedback block, a statistical filter block, or a program block. (That is, preferably each block is configured by user inputs to a template for one of these block types.) Preferably each kind of block also has the capability to call a user subroutine, and in fact the "program blocks" used in the presently preferred embodiment perform no other function.

[0127] The functional templates and data interface definitions for the most commonly used functions are pre-defined, but the user can also add code of his own if he wishes to do so. Providing standardized templates for the most commonly used functions expedites initial functional definition, and also facilitates maintenance, but sophisticated users are not prevented from writing their own customized functions (such as messaging).

[0128] Feedback blocks are used when a manipulated parameter must be adjusted to keep a measured parameter near a desired goal. Feedforward blocks are used when two parameters (which are not necessarily in a causal relation) are linked, *i.e.* when a manipulated parameter must be adjusted to keep it in some ratio (or other relation) to a measured parameter. Statistical filtering blocks are used, in the presently preferred embodiment, to provide the advantages of statistical process control, and to facilitate minimizing the number of control parameter adjustment actions.

[0129] Preferably a maximum number of blocks is predefined. (In the presently preferred embodiment, 200 blocks is the preset maximum, and this number is large enough to serve the control needs of several different systems simultaneously.) The imposition of a maximum helps to maintain the software, by limiting the number of functions which can be crowded into any one software structure, and by motivating users to delete obsolete block definitions.

[0130] Thus, a software structure like that described can be used to control several systems and/or used by several users. The provision of "ownership" identification for each block, which may optionally be combined with access privilege restrictions, advantageously helps to preserve maintainability in multi-user environments.

[0131] Figure 8 shows the preferred organization of the supervisor procedure 130. The top level loop (shown as a base cycle controller procedure 802), which calls the various blocks 851, 852, 853, ..., sequentially, is preferably a cycling procedure. For example, the dormant time waiting block 891 might be set, in the dimethyl terephthalate synthesis application described, so that the base cycle procedure 802 is executed every 15 minutes (and therefore the entire sequence of blocks 851 etc. is called for possible execution every 15 minutes). The base cycle procedure also preferably performs some overhead functions. For example, the base cycle procedure 802 optionally contains the appropriate commands for branching on interrupts 804, and for initialization after a start command 806. Secondly, the base cycle procedure 802, upon calling each block, will preferably look at the header of the block (which is stored as data in shared memory, as discussed below), and usually also at some external information, such as the system clock value or the time stamp of a variable, to see if that block is due to execute. In the presently preferred embodiment, each block will also have status flags which indicate whether it may be executed, and will also have timing options which can be used to the user to specify, for example, that a particular block is to be executed only every 175 minutes.

[0132] The base cycle procedure 802 is not the only procedure which is relatively "high-level" with respect to the blocks 851, 852, etc. The build-supervisor procedure 810 is able to present the user with templates 812, and to (effectively) change the operation of the blocks 851, 852, etc., by changing shared memory values in accordance with the user's inputs to the templates 812.

[0133] That is, the real time control actions of the supervisor procedure blocks are supervised by the base cycle procedure 802. The base cycle procedure is responsible for determining when blocks are on/off, when blocks should be initialized, and when blocks should be executed. It also controls the timing of the base scan through all blocks.

[0134] In the presently preferred embodiment, each time the base cycle procedure executes a block, it checks the block type label (in shared memory) and calls the appropriate subroutine. That is, a single block of executable code is used for all of the feedback blocks, and similarly another block of code is used for all the feedforward blocks, etc., so that all 200 blocks require only four subroutines for their standard functions. Each time the base cycle routine executes a feedback block, it calls up the user-defined parameter set for that particular block, and passes those parameters to the subroutine which performs feedback functions in accordance with those parameters.

#### Base Cycle Procedure

[0135] Figure 15 shows a flow chart of the logic preferably used in the base cycle procedure 802. The sequence of actions used in the main control program, when it is first started (*e.g.* by submitting it to a job queue) is:

- Check to see if more than 30 minutes has passed since the last control cycle in the supervisor procedure. If so, initialize all blocks whose status is "On", "Active", or "Just turned on". (Initialization sequence is given below). (This action is shown as 1502 in the flow chart of Figure 15.)

[0136] Start the control cycle loop: (This loop is shown in 1510 in the flow chart of Figure 15.)

- Set the system status to "Running-Computing".
- Compute the next cycle time by adding the base scan interval to the current time.

5 [0137] Start a loop through all blocks, starting with block number 1 and counting up to the maximum number of blocks (This loop is shown as 1520 in the flow chart of Figure 15):

- Check block status:
  - \* Get the switch status of the block. If the block is switching with an external switch parameter, get its status. (The switch status will be "On" if the external switch is on, or "Off" if the external switch is off.) If the loop is switched manually, the switch status is the same as the block's current status.
  - \* If the switch status is "On", "Active", "Toggled On", or "Just turned on", the block is on.
  - \* If the block is on, and the current block status is not "On" or "Just turned on", then the block is just being turned on. Set the Block Status to "Just turned on".
  - \* If the block is on, and the current block status is "On" or "Just turned on", then the block is continuing to be on. Set the Block Status to "On".
  - \* If the block is not on, it is off. Set the block status to "Off".

- If the block status is "Off", "Inactive", or "Failed", loop back up and start the next block.
- If the block status is "Just turned on", INITIALIZE the block (These steps are shown as 1524 in the flow chart of Figure 15):

- \* If the block has a measured variable, set the "Last measured time" equal to the current time of the measured variable.
- \* If the block has a Key block, set the "Key block time" equal to the "Last execution time" of the key block.
- \* Set the "Last execution time" of the block to the current time.
- \* If the block is a feedforward block, set the "Old measured value" equal to the current value of the measured variable.

- If the block has a measured variable, get its current time.
- If the block has a key block, get its last execution time.
- If the block timing option includes fixed interval, and if the elapsed time since the "last execution time" of the block is greater than or equal to the execution time interval, set the execute flag for the block.
- If the block timing option includes keying off the measured variable, and if the current time of the measured variable is more recent than the "last measured time" of the block, set the "last measured time" for the block equal to the current time of the measured variable, and set the execute flag for the block.
- If the block timing option includes keying off another block, and if the last execution time of the key block is more recent than the "key block time", set the "key block time" equal to the last execution time of the key block, and set the execute flag for the block.
- If the execute flag for the block is set, set the last execution time for the block equal to the current time, and execute the block. Only execute the block once, even if more than one timing option was satisfied. (The block execution procedures are discussed in greater detail below, and are shown generally as 1530 in the flow chart of Figure 15.)
- If more blocks need to be processed, loop back to the next block.

45 [0138] This is the end of the loop 1520 through all the blocks.

- Set the system status to "Running-Sleeping".
- Set a wake up timer for the next cycle time computed above, and go to sleep until the timer expires, or until awakened by a request to terminate the program.
- Wake up. Check to see if interrupted to terminate. If so, set the system status to "Terminated normally", and stop completely.
- If not terminated, branch back to the start of the control cycle loop 1510.

#### Sample Source Code

55 [0139] The source code for the procedure which actually performs this function, in the presently preferred embodiment, is as follows. Due to the formatting requirements of patent applications, some portions of this and other portions of source code provided herein contain statements which are wrapped across more than one line (and hence would

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need to be restored to single-line format, or appropriate leaders inserted, before being loaded for execution); but those skilled in the art will readily recognize these instances, and can readily correct them to produce formally perfect code.

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Table 1

```

5
C
C      Control.for
C
C      Main control program for the Advanced Control
C          System,
C      a high level optimization and control system
C      running on the Vax, using Vantage facilities.
C
C*****
C      Program Control
15
Include 'ACSS$includes:Block_parameters.inc/nolist'
Include 'ACSS$includes:Var_functions.inc/nolist'
Include 'ACSS$includes:Sys_functions.inc/nolist'
Include 'ACSS$includes:Manip_params.inc'
Include 'ACSS$includes:Meas_params.inc'
Include 'ACSS$includes:Filter_params.inc'
Include 'ACSS$includes:ACSServ.inc'
Include 'ACSS$includes:ACSSstatus.inc'
C
20
C
25
      Integer*4      Block
      Integer*4      Integer_Now
      Character*20   Character_now
      Integer*4      Timbuf(2)
      Integer*4      Measured_time_stamp
      Integer*4      Key_block_exec_time
      Logical*2      Execute_block
      Logical         Success
      Logical         First
      Logical         Debug_time
      Logical         Force_initialization
      Parameter       (Force_initialization = .True.)
      Logical         Dont_force_initialization
      Parameter       (Dont_force_initialization = .False.)
C
30
C
35
      Integer*2      Meas_type
      Integer*2      Meas_var
      Integer*2      filt_type
      Integer*2      Filt_var
C
40
C
45
      Integer*4      Event_flag_state
      Integer*4      Timer_flag
      Integer*4      Interrupt_flag
      Character*9    Cluster_name
      Parameter      ( Cluster_name = 'ACS_FLAGS' )
      Integer*4      Flag_mask
C
50
C
55
      Logical         Interrupt_flag_set
      Interrupt_flag_set() = Btest(Event_flag_state,1)
C

```

```

5
      Timer_flag = 64
      Interrupt_flag = 65
      First = .True.
      Flag_mask = 0
      Flag_mask = lset ( Flag_mask , 0 )
      Flag_mask = lset ( Flag_mask , 1 )

10
      C
      C...Record control program startup in the log file
      C
      Van_status = Vss$_from_ascii_time ( ' ' , Integer_now )
      Van_status = Vss$_to_ascii_time ( Integer_now ,
1                           Character_now )
      Write (6,*)
15
      ' Started the ACS control program at '
      1                           Character_now

      C
      C...Create the event flag cluster , clear interrupt flag
      C
      Sys_status = Sys$ascefc ( %Val(Timer_flag) ,
1           %descr(Cluster_name) , 0. , )
      Sys_status = sys$clref ( %val(Interrupt_flag) )

20
      C
      C...Check to see if ACS_control has been down for more than
      C  30 minutes. If so, initialize all active blocks.
      C
      Van_status = Vss$_from_ascii_time ( ' ' , Integer_now )
      If ( Integer_now - Integer_next_cycle .gt. 30*60 ) Then
        Do 10 Block = 1,Max_blocks
          If ( ( Block_status(Block)(1:2) .eq. 'On' ) .or.
30
          1   ( Block_status(Block)(1:6) .eq. 'Active' ) .or.
          1   ( Block_status(Block)(1:14) .eq. 'Just turned on' ) )
          1   Call Initialize_block ( Block )
        10   Continue
      End If
      C
      C....The main block control loop
      '1   Continue
      C
      C....Set system status to Running
      C
      System_status = 'Running-Computing  '
      C
      C...Set Wake up time to ACS_base_scan minutes from now
      C
      Van_status = Vss$_from_ascii_time ( ' ' , Integer_now )
      Van_status = Vss$_to_ascii_time ( Integer_now ,
1                           Character_now )
      Integer_next_cycle = Integer_now + ACS_base_scan*60
      Call Vss$_get_systime ( Integer_next_cycle , Timbuf )

50
      C
      C....Loop through all the blocks
      C
      Do 100 Block = 1,Max_blocks

```

55

```

C
C....Update the block status from the info coming from PCS
C
5      Call Check_block_status ( Block )
C
C...Check the block status, if inactive or off, skip it
C
10     If ( ( Block_status(Block)(1:8) .eq. 'Inactive' ) .or.
11         ( Block_status(Block)(1:6) .eq. 'Failed' ) .or.
12         ( Block_status(Block)(1:10) .eq. 'On-holding' ) .or.
13         ( Block_status(Block)(1:3) .eq. 'Off' ) ) Then
14     Go To 100
15     End If
16     If ( First )
17     1   write(6,*): 'Block: ',block,' Status = '
18     1 block_status(block)

C
20     C...If the block has just been turned on, initialize it
C
25     If (Block_status(Block)(1:14) .eq. 'Just turned on' ) Then
26     Call Initialize_block( Block )
27     End If
C
C....Check to see if it is time to execute the block
C
30     C..... Use appropriate calls for the block type
C
35     If (
36         ( Block_type ( Block )(1:8) .eq. 'Feedback' ) .or.
37         ( Block_type ( Block )(1:11) .eq. 'Feedforward' ) .or.
38         ( Block_type ( Block )(1:7) .eq. 'Program' )
39     ) Then
40     ACS_status = ACS_get_meas_var_type ( Block , Meas_type )
41     If ( Meas_type .eq. Cur_val_var ) Then
42     ACS_status = ACS_get_meas_var_num ( Block , Meas_var )
43     Van_status = Vss$g_curttime ( Meas_var ,
44                                     Measured_time_stamp )
45     Else
46     Measured_time_stamp = 0
47     End If
C
48     Else If (
49         ( Block_type ( Block )(1:8) .eq. 'Shewhart' )
50     ) Then
51     ACS_status = ACS_get_filtered_var_type ( Block , Filt_type )
52     If ( Filt_type .eq. Van_var_filter ) Then
53     ACS_status = ACS_get_filtered_var_num ( Block , Filt_var )
54     Van_status = Vss$g_curttime ( Filt_var ,
55                                     Measured_time_stamp )
56     Else
57     Measured_time_stamp = 0

```

```

        End If
    End If
C
5    C...Get exec time of key block, if defined
C
    Key_block = Var_num2(Block)
    If ( Key_block .ne. Empty ) Then
        Key_block_exec_time = Last_execution_time ( Key_block )
10    Else
        Key_block_exec_time = 0
    End If
C
    Execute_block = .False.
15    If ( First .eq. .True. ) Then
        Var_STATUS = vss$_to_ascii_time ( Integer_now , Debug_time )
        write(6,*) ' Block = ',block
        write(6,*) 'Integer_now = ',Debug_time
        Var_STATUS = vss$_to_ascii_time ( last_execution_time(block)
20        1 , Debug_time )
        write(6,*) 'last_execution_time = ',debug_time
        Var_STATUS = vss$_to_ascii_time ((-1)*Frequency(block)*60
        1 , Debug_time )
        write(6,*) 'Frequency(block) = ',Debug_time
        Var_STATUS = vss$_to_ascii_time ( last_measured_time(block)
25        1 , Debug_time )
        write(6,*) 'last_measured_time = ',Debug_time
        Var_STATUS = vss$_to_ascii_time ( measured_time_stamp
        1 , Debug_time )
        write(6,*) 'measured_time_stamp = ',Debug_time
        write(6,*) 'timing_option = ', Var_num3(Block)
        d
        End If
C
35    I_timing_option = Var_num3(Block)
    If ( ( I_timing_option .eq. Interval ) .and.
        1   ( Integer_now - last_execution_time(Block) .ge.
        1       Frequency(Block)*60 ) ) Then
        1       Last_execution_time(Block) = Integer_now
        Last_measured_time(Block) = Measured_time_stamp
        Execute_block = .True.
40
C
        Else If ( I_timing_option .eq.
45        1           Key_off_measured_variable )Then
        If ( Measured_time_stamp .gt.
        1           Last_measured_time(Block) ) Then
            Last_execution_time(Block) = Integer_now
            Last_measured_time(Block) = Measured_time_stamp
            Execute_block = .True.
50
        End If
C
        Else If ( I_timing_option .eq.
55        1           Key_off_ACS_block ) Then
            If ( Key_block_exec_time .gt.

```

```

1           Fix_time(Block) > Then
5           Last_execution_time(Block) = Integer_now
           Last_measured_time(Block) = Measured_time_stamp
           Fix_time(block) = Key_block_exec_time
           Execute_block = .True.
      End If

10      Else If ( I_timing_option .eq.
11           Intrvl_and_key_off_ACS_block) Then
12          If (
13             ( Key_block_exec_time .gt.
14               Fix_time(Block) ) .or.
15             ( Integer_now - Last_execution_time(Block) .ge.
16               Frequency(Block)*60)
17           ) Then
18             Last_execution_time(Block) = Integer_now
19             Last_measured_time(Block) = Measured_time_stamp
20             Fix_time(block) = Key_block_exec_time
21             Execute_block = .True.
22           End If

25      Else If ( I_timing_option .eq.
26           Intrvl_and_key_off_meas_var) Then
27          If (
28             ( Measured_time_stamp .gt.
29               Last_measured_time(Block) ) .or.
30             ( Integer_now - Last_execution_time(Block) .ge.
31               Frequency(Block)*60)
32           ) Then
33             Last_execution_time(Block) = Integer_now
34             Last_measured_time(Block) = Measured_time_stamp
35             Fix_time(block) = Key_block_exec_time
36             Execute_block = .True.
37           End If

40      Else If ( I_timing_option .eq.
41           Key_off_meas_var_end_block) Then
42          If (
43             ( Key_block_exec_time .gt.
44               Fix_time(Block) ) .or.
45             ( Measured_time_stamp .gt.
46               Last_measured_time(Block) )
47           ) Then
48             Last_execution_time(Block) = Integer_now
49             Last_measured_time(Block) = Measured_time_stamp
50             Fix_time(block) = Key_block_exec_time
51             Execute_block = .True.
52           End If

55      Else If ( I_timing_option .eq.
56           Intrvl_and_Key_meas_and_block) Then
57          If (

```

```

1      ( Key_block_exec_time .gt.
1          Fix_time(Block) ) .or.
1      ( Measured_time_stamp .gt.
1          Last_measured_time(Block) ) .or.
1      ( Integer_now - Last_execution_time(Block) .ge.
1          Frequency(Block)*60)
1  ) Then
5      Last_execution_time(Block) = Integer_now
10      Last_measured_time(Block) = Measured_time_stamp
1      Fix_time(Block) = Key_block_exec_time
1      Execute_block = .True.
1      End If
1      End If
15      C
1      C...If Time to execute, call the Subroutine for the appropriate block type
1      C
20      If ( Execute_block .eq. .True. ) Then
1          If ( Block_type(Block)(1:11) .eq. 'Feedforward' ) then
1              Call Feedforward_block(Block)
1          Else If ( Block_type(Block)(1:8) .eq. 'Feedback' ) then
1              Call Feedback_block(Block)
1          Else If ( Block_type(Block)(1:7) .eq. 'Program' ) then
1              Call Program_block ( Block )
1          Else if ( Block_type(Block)(1:8) .eq. 'Shewhart' ) then
1              Call Shewhart_block( Block )
1          End If
1      End If
25      C
30      100 Continue
30      C
30      C...All Blocks checked and executed if needed; go to sleep until needed
30      C
35      102 Continue
35      C
35      Sys_status = Sys$setimr ( %val(Timer_flag) , %ref(Timbuf),, )
35      If ( Sys_status .eq. %loc(Ss$normal) ) Then
35      d      Write(6,*) ' Successfully set timer.'
35      Else
40      Write(6,*) ' Error return from setimr in Control at ',
35          Character_now
35      End If
35      C
45      System_status = 'Running-Sleeping      '
45      Sys_status = Sys$uflor ( %val(Timer_flag) , %val(Flag_mask) )
45      If ( .not. Sys_status ) Call Lib$signal(%val(Sys_status))
45      C
50      Sys_status = sys$readdef ( %val(Timer_flag) ,
45          %ref(Event_flag_state) )
50      If ( .not. Sys_status ) Call Lib$signal(%val(Sys_status))
50      C
55      If ( ( Sys_status .ne. %loc(Ss$wasclr) ) .and.
55          ( Sys_status .ne. %loc(Ss$wasset) ) ) Then

```

```

      Write(6,*) ' Problem reading event flag status'
      End If
      5
      C
      C..Test the interrupt bit- if set, process the request
      C
      If ( interrupt_flag_set() ) Then
      d      Write(6,*) 'got an interrupt'
      10     Call Shutdown ( Event_flag_state )
      Else
      d      Write(6,*) 'Timer expired.'
      End If
      15
      C
      first = .false.
      Go To 1
      C
      End
      20

```

25 Build-Supervisor Procedure

[0140] The build-supervisor procedure 810 presents templates 812 to the user and stores the user responses to these templates in a "global section" portion of memory (i.e. a shared or commonly accessible portion of memory). That is, the user inputs to the templates for the various blocks 851, 852, etc., are stored where the base cycle procedure 802 can access them and the build-supervisor procedure 810 can also access them. Thus, an authorized user can at any time interactively call up data from shared memory space 814, see these parameters in the context of the templates 812, and modify the functions of the various blocks 852, 853, etc. and/or define new blocks (and/or delete existing blocks), while the base cycle procedure 802 continues to call the various blocks on the appropriate schedule. That is, the base cycle procedure 802 is preferably a cycling procedure which satisfies the real-time process control demands of the underlying process, while the build-supervisor procedure 810 retains the capability for reconfiguring the operation of the various blocks in the supervisor, according to user input.

[0141] It should be noted that the structural features and advantages of the build-supervisor procedure are not entirely separate from those of the supervisor procedure. The two procedures are preferably operated separately, but they provide an advantageous combination. The features of the supervisor procedure are partly designed to advantageously facilitate use of the build-supervisor procedure, and the features of the build-supervisor procedure are partly designed to advantageously facilitate use of the supervisor procedure.

[0142] In the presently preferred embodiment, the nexus between the build-supervisor procedure and the supervisor procedure is somewhat different from the nexus between the build-expert procedure and the operating expert procedures. The user entries made into the more constrained parts of the templates can be transferred fairly directly to the operating supervisor procedure: the build-supervisor procedure stores values (corresponding to the data input by the user in the accessible fields of the templates) in a section of memory, which is immediately accessible by the supervisor procedure as soon as the stored status value for the block is changed to "Active". By contrast, if the customized user routines (including the expert routines generated by the build-expert software) are modified, they must be compiled and linked with the supervisor procedure.

[0143] The build-supervisor procedure 810 preferably also has the capability to stop or restart the base cycle procedure 802, independently of whether the build-supervisor procedure 810 has updated the shared memory 814 in accordance with user inputs to templates 812.

55 Top-Level Menu

[0144] The user who begins an interaction with the build-supervisor procedure is first presented with a menu which (in the presently preferred embodiment) resembles that shown as Figure 16. This menu provides options which permit the user to setup (or modify) blocks, to monitor blocks, to call block-management utilities, to exit, or to go into a structured

environment for writing user programs.

[0145] If the user chooses block setup, he next sees a menu like that shown in Figure 9. This menu is presented to the user by the build-supervisor procedure 810 to select a specific existing template 812' (i.e. a template with the previously defined data values of a particular block are shown in the appropriate fields of the template) or a blank template 812 of a given type to provide user inputs to define or modify a block 851, 852, etc.

[0146] This form allows the user to choose which block to enter setup parameters for, and, if the block is a new one, allows a choice of which type block it will be. To go back to the previous form (in this case the top-level menu), he can press the "-" key on the keypad.

[0147] To set up a new block, the user can either enter a block number which he knows is not in use, or the build-supervisor procedure will provide him with the lowest number block which is not in use. To enter a block number, the user can simply type the number in the block number field and press the return key. To get the build-supervisor procedure to find the lowest number unused block, the user can press keypad 8. The cursor will move to the block type field and the build-supervisor procedure will request that the user enter the number from the list for the type of block desired. The build-supervisor procedure will then present the user with a block setup form for that block type. If the user mistakenly enters a block number which is already in use, the build-supervisor procedure will go directly to the setup form for that block, but the user can simply press keypad minus on the setup form to go back to the block setup selection form and try again. To enter or modify setup parameters for an existing block, the user can simply enter the block number and press the return key, and the build-supervisor procedure will present the block setup form for that block.

[0148] In the best mode as presently practiced, all four block setup forms have some common features. Keypad 9 will move the cursor from anywhere on the form up to the block number field. Keypad 8 will find the lowest number available block and set it up as the same block type as the form showing on the screen. Keypad 7 tests all the parameters on the block and changes the block status to switch it on or off, or requests new data if the user has not yet supplied it. (In addition, many of the parameters are checked for gross error as the user enters them.)

[0149] The various block setup forms shown as Figures 10 through 13 will be individually described below; but first, some features common to some or all of the block setup forms, and some features characteristic of the operation of the blocks thus defined, will be described.

[0150] When a block is turned on, the block status will not go directly to "On." (The full system of block status options (in this embodiment) is described below.) Depending on how the block is set up to be switched on and off, the status will change to "Toggled on" or "Active". The base cycle procedure will update the status as the block is executed, changing to "Just turned on" and then to "On". When turning a block off, the status will change to "Off" or "Inactive", again depending on how the block is set up to switch. These status sequencing rules facilitate use of initialization and/or shutdown steps in controlling block functionality.

[0151] Any time a parameter is entered or changed on a setup form, the block status will be set to "Inactive." This means that the block parameters have not been checked to assure that everything needed has been entered and is consistent. If a parameter is changed on a block which is currently on, the block must be toggled from "Inactive" to "Active" or "Toggled On" using Keypad 7.

#### Data Source Specification

[0152] The templates presented to the user for block customization include a standardized data interface. The data values to be used by the supervisor are specified in the standard interface by two identifiers. The first identifies which (software) system and type of value is desired. The value of a setpoint in a particular distributed control system, the value of a sensor measurement in a particular process monitoring system, the value of a constraint from a process control or supervisor system, and time averages of sensor measurements from a particular historical database are examples of this. The second identifier specifies which one of that type of value is desired, for example the loop number in the distributed control system.

[0153] For example, in Figure 10 the user has entered "4" in the highlighted area 1002 after the phrase "Measured Variable Type:". This particular identifier (i.e. the value entered in this field by the user) indicates that the variable type here is a current value of a variable from the historical database, and the build-supervisor procedure adds an abbreviated indication of this ("Current Val Hist Dbase Var #") onto the user's screen as soon as the user has entered this value in the field 1002. (If the user entered a different code in the field, a different short legend might be shown. For example, as seen in Figure 10, the user has indicated a variable type of "2" after the phrase "Manipulated Var Type", indicating that the manipulated variable is to be a loop goal of the DMT control system.) As the second identifier, the user has indicated a value of "2990" in field 1004, to indicate (in this example) which particular Database variable's current value is to be used. For this identifier to, the build-supervisor procedure adds an abbreviated indication of its interpretation of this identifier ("DMT PRD MFB SHWRT DEVIAT") onto the user's screen as soon as the user has entered this value in the field 1004.

[0154] Data values specified through the standard interface may be used as measured values, manipulated values,

or as switch status values indicating an on/off status. Preferably the interface allows the user to specify data in any of the relevant process control and data collection systems used for the process, or for related processes. Preferably, the interface also allows specification of data (both current and historical) in a historical process database. Since multiple control systems (or even multiple historical databases) may be relevant to the process, the standard interface greatly facilitates the use of relevant data from a wide variety of sources.

#### Block Timing Information

[0155] In the presently preferred embodiment, all blocks except the Shewhart block provide the same block timing options. Block timing determines when a block will perform its control actions. The build-supervisor procedure provides three fundamental block timing options, which can be used in any combination, providing a total of 7 block timing options. The three fundamental options are:

Fixed Time Interval: the block will execute at a fixed time interval. The user specifies the time interval, *e.g.* in minutes. (Note that a combination of this option and the following has been specified in the example of Figure 13, by the user's entry of "5" into field 1306.)

Key Off Measured Variable: the block will execute every time a new value is entered into the process database for the measured variable. The measured variable must be a "sampled" type variable. (Note that this option has been specified in the example of Figure 10, by the user's entry of "2" into field 1006.)

Key Off Another ACS Block: the block will execute every time a (specified) lower numbered block executes. The user specifies which block will be the key block. Any combination of one, two or three timing options can be used. Blocks using a combination timing option execute whenever any of the specified timing options are satisfied. (Note that this option has been specified in the example of Figure 11, by the user's entry of "3" into field 1006.)

[0156] Block timing options are represented on the setup forms by a number code. The user enters the number code corresponding to the desired timing option. If the timing option includes fixed interval timing, an execution time interval must also be specified. If the block is to key off another block, the key block number must be specified.

[0157] In future alternative embodiments, the block timing options set forth here may be especially advantageous in multi-processor embodiments: the separation of the control action specifications in multiple blocks shows the inherent parallelism of the problem, while the keying options in which one block keys off another show the block sequencing constraints which delimit the parallelism. The standardized data interface used in the presently preferred embodiment may also be advantageous in this context, by allowing block execution to be keyed off events external to the supervisor.

#### Primary Block Switching

[0158] The supervisor procedure provides several ways to switch block actions on and off. If the block needs to be turned on and off by an operator, the build-supervisor procedure allows the user to specify an external switch system and a switchable entity within that system which the block on/off status is to follow. For example, the user may specify a specific control system and a loop number within that system. The block will turn on when that loop is on, and off when that loop is off. The standardized data interface allows any accessible control system to act as the switch system. As a further alternative, the blocks can be set to switch on and off only under the control of the developer (*i.e.* under the control of the build-supervisor user). In this case, the block can only be switched using the toggle on/off function on the block setup form.

[0159] The external switch system is represented on the block setup forms by a number. The user enters the number corresponding to the external switch system he wants to use. The entity within the switch system (*e.g.* the loop number) is entered in the next field. (In the example of Figure 10, the user entries in fields 1008 and 1010 have specified an external switching variable.) If the block is to be turned on and off only from the build-supervisor procedure setup form, a zero is entered for the switch system number, and the word "Manual" will show in the field for the switch entity number. (This option has been selected in the example of Figure 13.)

#### Secondary Block Switching

[0160] The supervisor also provides secondary means of controlling block execution. Blocks which have been turned "on" by their primary switch controls may be "selected", "de-selected", or "held" by programmatic requests. The status of selected blocks changes to "On-selected". Selected blocks continue to function as if they were "On". The status of blocks which are deselected by programmatic request changes to "On-deselected". De-selected blocks take no control action. However, they differ from blocks which are "off" because they continue to maintain all their internal information so that they are always ready to execute if "selected". The status of blocks which are held by programmatic request changes to "on-holding". The programmatic request includes the length of time the block is stay on hold. Blocks which are holding act as if they were off. When the holding time expires, the status of holding blocks changes to "Just turned

on," and they initialize.

[0161] One advantage of these block switching options is that they provide a way to embed alternative control strategies in the supervisor procedure. That is, control strategies can be readily changed merely by selecting some blocks in the supervisor procedure and/or deselecting other blocks. This is advantageous in terms of software documentation, since it means that alternative control strategies can be documented and maintained within the same software structure. It is also advantageous in interfacing to other procedures: for example, the expert systems called by the presently preferred embodiment will frequently take action by selecting and/or deselecting blocks of the supervisor procedure.

[0162] These block control options facilitate the use of one supervisor procedure to interface to multiple controllers, and the use of one supervisor procedure by different users to control different processes. The block status system permits one or more blocks to be updated without interfering with the running supervisor process; in fact, in optional environments, multiple users could be permitted to update different blocks at the same time.

#### Block Description Fields

[0163] All blocks allow the user to enter three descriptive fields. These fields are for user reference and can be searched when printing lists of block parameters. They have no effect on block actions. The "control application name" field allows the user to group blocks that are part of the same control application by giving them all the same application name. (In the example of Figure 10, the user entry in field 1014 has specified "MFB Control". Note that the examples of Figures 11, 12, and 13 show corresponding entries in this field.) The block description field allows the user to describe the block's specific action or purpose. (In the example of Figure 13, the user entry in field 1316 has explained that this is a "Block to run expert deciding where to take MFB feedback action".) The ownership field specifies which user has control of the block. (In the example of Figure 10, the user entry in field 1012 has specified "Skeirk". Note that the examples of Figures 11, 12, and 13 show corresponding entries in this field.) This field facilitates use of the organization described in environments where multiple users are defining blocks which run within the same supervisor procedure.

[0164] Of course, in multi-user environments it may be desirable to allow some users a greater degree of access than others. Thus, for example, some users may be authorized to edit a block, while others maybe authorized to toggle the block on or off but not to edit it, and others maybe authorized to monitor block operation but not authorized to change it. Similarly, access to expert systems may be constrained by giving greater authorization to some users than to others; some users may be permitted to make calls to the expert system but not to edit the rulebase, and other users may not be permitted to do either. In the presently preferred embodiment, all of these choices can readily be implemented by using the file ownership and access control list options available in the VMS operating systems, but of course this functionality could be implemented in many other ways instead.

#### Action Logging

[0165] The supervisor procedure provides a means of reporting control actions and/or logging them in a file for recall. Control action messages are written by a user routine. Control blocks call user routines after their control actions are complete, and pass data regarding their actions. The action log file field allows the user to enter the name of the file to which logging messages will be written. The same log file can be used for more than one block (e.g., if the two blocks' actions are part of the same control application). (For example, note that field 1018 in the example of Figure 10 and field 1118 in the example of Figure 11 both specify "MFBCONTROL" as the action logging file.) The log file name is limited to letter and number characters, and no spaces are allowed (except after the end of the name).

#### Block Status

[0166] Note that, in the example of Figure 10, a block status of "On-selected" is displayed in area 1020. This is not a field into which the user can directly enter data, but it will change in response to user actions (e.g., the user can toggle the block on or off by hitting keypad 7). The block status codes used in the presently preferred embodiment reflect several aspects of block setup and execution, including:

Proper configuration of block parameters;  
On/off status of block;  
Failure of block actions; and  
Failure of user routines.

[0167] Some common block status values are:

[0168] "Inactive:" this indicates that the block has not been properly configured and toggled on, or that a parameter was changed. This is also the normal "off" status of a block which has been configured to switch on and off with a

switch system variable, if the user toggles it off from the setup form.

[0169] "On:" this is the normal status for blocks which are performing their control actions.

[0170] "Off:" this is the normal status, for a block which has been configured to switch on and off with a switch system variable, when that variable is in its off state. This is also the normal status for blocks which are configured to switch on and off through the setup form only and have been toggled off from the setup form.

[0171] "Active:" this is the status to which a block is toggled on if it is configured to switch on and off with a switch system variable. This status will change on the next cycle of the control program, to "On" or to another value, depending on the state of the switch system variable.

[0172] "Toggled on:" this is the status to which a block is toggled on if it is configured to switch on and off through the setup form only. This status will change on the next cycle of the control program.

[0173] "Just turned on:" this is a normal transition state for blocks going from an "off" status (eg: off, inactive) to "On" status. Blocks whose status is "Just turned on" will be initialized by the base cycle procedure, which resets the last execution time and the measured variable and key block times used for block timing. Feedforward blocks initialize the "old" measured variable value to the current value.

[0174] "On-selected": indicates that a block which is on has been selected by a programmatic request. The block continues to function as if it were On.

[0175] "On-deselected": indicates that a block which is on has been de-selected by a programmatic request. The block takes no control actions, but continues to maintain its internal parameters as if it were On. This keeps the block ready to act if selected.

[0176] "On-holding": indicates that a block has been put on hold for a specified length of time by a programmatic request. The block takes no control action. A block that has been holding will re-initialize and go back to "On" status when the holding period expires.

[0177] "On-Failed usr routin:" this status indicates that a user routine called by this block had a fatal error which was bypassed by the supervisor procedure on the most recent execution of the block. Fatal errors in user routines are reported in the control program log file (not the same as action log files), and can be reviewed using the "List log file" option on the System Functions screen, described in the section on block monitoring.

[0178] "On-Recovrd usr Error:" this indicates that a fatal error was bypassed in the user routine, but that the user routine ran successfully on a later execution. Again, the log file will give more details about what happened.

[0179] "On-Err .... :" many abnormal status values can indicate that problems were encountered in block execution, e.g. problems in the input or output of data to control systems. The latter part of the status field gives some indication of the problem. Most such errors are also recorded in the control program log file.

[0180] Various other block status values can readily be inserted, along the lines demonstrated by these examples.

### Feedback Blocks

[0181] Figure 10 shows a sample of a template B12 presented to the user to define a feedback block. In the specific example shown, the block being worked on is block number three of the 200 available blocks 851, 852, etc., and the various data values shown in this Figure reflect the entries which have been made at some time to define this particular block.

[0182] The feedback block provides proportional feedback action. In feedback action, the user specifies a measured value (called the "measured variable") and a goal value (setpoint) at which he wants to maintain it. Feedback action calculates the "error" in the measured variable (measured variable value - goal), and computes its action by multiplying the error times the "proportional gain". The current value of the "manipulated variable" is changed by the amount of the calculated action.

[0183] The basic feedback action can be altered by several additional parameters. A deadband around the goal can be specified. If the measured value falls within plus or minus the deadband of goal, no action is taken. The amount of action taken can be limited to a fixed amount. The range over which the value of the manipulated variable can be changed can be limited to keep it within operable limits. Screening limits can be specified on the measured variable value, in which case measured values outside the screening limits will be ignored. Block timing and switching and the block description fields follow the general outlines given above.

[0184] Specifying a feedback block on the block setup selection form (Figure 9) brings up a feedback block setup form, as shown in Figure 10.

### Parameters

[0185] The parameters which the user is asked to specify include:

[0186] Measured variable type: a number code representing the software system and the type of entity which the block should use for the measured variable. (A sample response might be a number code indicating a Historical da-

tabase variable.)

[0187] Measured variable number: the number of the entity within the specified system which the block will use for the measured variable. For example, if the measured variable type is a historical database variable, the measured variable number is the number of the variable in the historical database. After the measured variable type is entered, the label next to this field will show what type of data is needed. When the measured variable number is entered, other fields will also be filled in: the name and units for the measured variable, deadband and goal; units and default values for the max and min measured values. If block timing is to key off entry of new data into the measured variable, only discretely sampled variable types can be used.

[0188] Goal: the value at which the measured variable is to be "held". The value is entered in entered in the units of the measured variable.

[0189] Manipulated variable type: a number code representing the "target system" - the software package and the type of entity which the block should manipulate. Examples are: control system loop goal, historical database variable, a setpoint in a distributed control system, or a setpoint for a programmable loop controller.

[0190] Manipulated variable number: the number of the entity within the target system which the block will manipulate. For example, if the manipulated variable type is a control system loop goal, the manipulated variable number would be the number of the loop whose goal is to be changed. The label next to this field will show what type of information is needed; in this case the label would show "Cont Sys loop #".

[0191] Proportional gain: the constant relating the change in the manipulated variable to the error. The units of the gain are shown to the right of the field after the measured and manipulated variable have been specified. Control action is calculated:

$$\text{Error} = [\text{Measured variable value} - \text{goal value}]$$

$$\text{Manipulated delta} = \text{Error} * [\text{Proportional gain}]$$

[0192] The manipulated delta is added (subject to limits) to the current value of the manipulated variable.

[0193] Deadband: A range around the goal value. If the value of the measured variable falls a range defined by the goal plus or minus the deadband, no action is taken.

[0194] Timing option, execution time interval, and Key block number: these parameters are those described above.

[0195] External switch system and switch number: these parameters are described above.

[0196] Maximum manip delta: the maximum change that can be made in the manipulated variable's value in one control action.

[0197] Minimum and maximum value of the manipulated variable: limit values outside which control action will not move the value of the manipulated variable. If a computer control action would put the manipulated value outside the limits, the value is set equal to the limit. If the manipulated value is moved outside the limits (by operator action, for example) the next control action will return the value to within the limits.

[0198] Minimum and maximum value of measured variable: Screening limits for reasonable values of the measured variable. Any time the measured variable value falls outside these limits, the value will be ignored and no action is taken.

[0199] Action log file: this specifies the name of the log file for action logging.

#### Feedback Block Operation

[0200] The sequence of actions performed by each feedback block, when executed by the base cycle routine, is:

- If block status is "On-deselected", do no further actions;
- Get the current value of the measured variable (If not accessible, set status to "On-err...." and do no further actions);
- Get the current time stamp of the measured variable;
- Test the value of the measured variable. If it is outside the minimum and maximum allowed values, set status to "On-msrd out of lims" and do no further actions.
- Get the current value of the manipulated variable. If not accessible, set status to "On-err ...." and do no further actions.
- Compute the error (= Measured value - Goal). If absolute value is less than the deadband, do no further actions.
- Compute the change in the manipulated variable:

$$\text{Delta\_manip} = \text{Error} * \text{proportional Gain}$$

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If the absolute delta is greater than the maximum allowed delta, set it equal to the maximum (maintaining proper sign).

- Compute the new value of the manipulated variable:

5

New manip value = Current manip value + delta\_manip

If the value is outside the max/min limits, set it equal to the nearest limit. If limited, recompute the delta using the limit.

- Change the manipulated variable value to the new value computed. If not accessible, change status to "On-err ... " and do no further actions.
- Load user array values for use by the user routine.
- If delta\_manip is not zero, update the past action values and times.
- Call the user routine.

15

### Data passed to the user routine

[0201] In the presently preferred embodiment, each feedback block is able to pass information about its actions to the user routine, by using a commonly accessible memory block named "User\_vars." (The use of this data by the user routines is described in more detail below.) The data passed by the feedback block may include:

20

"User\_integer(1)" - the time stamp of the measured variable (from the database);

"User\_integer(2)" - the time the action was taken;

"User\_real(1)" - the change in the value of the manipulated variable;

"User\_real(2)" - the computed error; and

25

"User\_character(1)" - a string (alpha-numeric) sequence which describes the block type; for feedback blocks this is set to be = 'Feedback'.

### Sample Source Code

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[0202] The source code for the procedure which actually performs this function, in the presently preferred embodiment, is as follows.

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40

45

50

55

Table 2

```

5
C
C      Feedback_block.for
C
10
C      ACS subroutine to do feedback action on the Vax, communicating
C      directly with the target system.
C
C
15
C*****+
C
C      Subroutine Feedback_block ( Block )
C
20
C
C      Include 'ACSS$includes:Block_parameters.inc/nolist'
C      Include 'ACSS$includes:Var_functions.inc/nolist'
C      Include 'ACSS$includes:User_vars.inc/nolist'
C      Include 'ACSS$includes:ACSstatus.inc/nolist'
C      Include 'ACSS$includes:ACSServ.inc'
C
25
C      Include 'Acs$includes:Tlserv.inc'
C      Include 'Acs$includes:Tlstatus.inc'
C      Include 'ACSS$includes:Manip_params.inc'
C      Include 'ACSS$includes:Meas_params.inc'
C
30
C
C
35
C      Integer*2      Meas_var_system
C      Integer*2      Meas_var_number
C      Integer*2      Manip_var_system
C      Integer*2      Manip_var_number
C      Integer*4      Block
C      Integer*4      Measured_time_stamp
C      Integer*4      Integer_Now
C
40
C      Character*20   now_time
C      Real*4         Measured_value
C      Real*4         Current_manipulated_value
C      Real*4         New_manipulated_value
C
45
C
C...Special handling for 'On-deselected' status - do nothing
C
50
C      If ( Block_status(Block)(1:13) .eq. 'On-deselected' ) Then
C          Return
C      End If

```

```

C
5      ACS_Status = ACS_get_meas_var_type ( Block , MEAS_VAR_system )
      Manip_var_system = Manipulated_variable(Block)
      Manip_var_number = New_manipulated_variable(Block)
D      Write(6,*) ' Calling new_feedback - block = ',block
C
10     C...Get the measured value
C
15     Var_Status = Vass_from_ascii_time ( ' ' , Integer_now )
      Var_Status = Vass_to_ascii_time( Integer_now , now_time )
C
16     C...Measured Value is TPA PCS loop goal
C
17     If ( Meas_var_system .eq. PCS_TPA_Loop_goal ) Then
18         ACS_Status = ACS_get_pcs_goal( 'TPA      ' ,
19             Measured_variable(Block) , Measured_value )
20         If ( ACS_Status .ne. %loc(ACS_success) ) Then
21             C.....If PCS goal value not available, don't execute
22                 Block_Status(Block) = 'On-Err-PCS goal get'
23                 Write( 6, *) 'Feedback exit due to measured var not available'
24                 write(6,*)" ACS Block: ',block,' at: ',now_time
25                 Return
26             End If
C
27             C...Measured Value is DMT PCS loop goal
C
28             Else If ( MEAS_var_system .eq. PCS_DMT_Loop_goal ) Then
29                 ACS_Status = ACS_get_pcs_goal( 'DMT      ' ,
30                     Measured_variable(Block) , Measured_value )
31                 If ( ACS_Status .ne. %loc(ACS_success) ) Then
32                     C.....If PCS goal value not available, don't execute
33                         Block_Status(Block) = 'On-Err-PCS goal get'
34                         Write( 6, *) 'Feedback exit due to measured var not available'
35                         write(6,*)" ACS Block: ',block,' at: ',now_time
36                         Return
37                     End If
C
38             C...Measured Value is ACS block goal
C
39             Else If ( MEAS_var_system .eq. ACS_block_goal ) Then
40                 ACS_Status = ACS_get_goal (
41                     Measured_variable(Block) , Measured_value )
42                 If ( ACS_Status .ne. %loc(ACS_success) ) Then
43                     C.....If ACS goal Value not available, don't execute
44                         Block_Status(Block) = 'On-Err-ACS goal get'
45                         Write( 6, *) 'Feedback exit due to measured var not available'
46                         write(6,*)" ACS Block: ',block,' at: ',now_time
47                         Return
48                     End If
C

```

```

C...Measured value is Vantage variable
C
5      Else If ( Meas_var_system .eq. cur_vat_Van_var ) Then
          Van_Status = Vss9g_current( Measured_variable(Block) ,
1           Measured_value )
          If ( Van_Status .ne. %loc(vss_normal) ) Then
C.....If Variable Value not available, don't execute
          Block_status(Block) = 'On-Failed Hard var'
          Write( 6, * ) 'Feedback exit due to measured var not available'
          write(6,*)' ACS Block: ',block,' at: ',now_time
          Return
          End If
15
C
          end if
          Van_Status = Vss9g_curtim ( Measured_variable(Block) ,
1           Measured_time_stamp )
C
20      C....Check the Measured variable to see if it is within limits
C
          If ( (Measured_value .lt. Measured_min(block) ) .or.
1           (Measured_value .gt. Measured_max(block) ) ) Then
C.....Reject the data point
          Write( 6, * ) 'Feedback exit due to out of limits measured'
          write(6,*)' ACS Block: ',block,' at: ',now_time
          Block_Status(Block) = 'On-Hard out of lims'
          Return
          End If
30
C
C
C...Get the current manipulated value
C
C
35      C...Target is TPA PCS loop goal
C
          If ( Manip_var_system .eq. PCS_TPA_Loop ) Then
              ACS_Status = ACS_get_pcs_goal( 'TPA' ,
1               Manip_var_number , Current_manipulated_value , )
              If ( ACS_Status .ne. %loc(ACS_success) ) Then
C.....If PCS goal value not available, don't execute
              Block_Status(Block) = 'On-Err-PCS goal get'
              Return
              End If
C
C...Target is DMT PCS loop goal
C
40
          Else If ( Manip_var_system .eq. PCS_DMT_Loop ) Then
              ACS_Status = ACS_get_pcs_goal( 'DMT' ,
1               Manip_var_number , Current_manipulated_value )
              If ( ACS_Status .ne. %loc(ACS_success) ) Then
C.....If PCS goal value not available, don't execute

```

```

      Block_status(Block) = 'On-Err-PCS goal get'
      Return
End If
5
C
C...Target is ACS block goal
C
Else If ( Manip_var_system .eq. ACS_block ) Then
10      ACS_status = ACS_get_goal ( Manip_var_number ,
1           Current_manipulated_value )
      If ( ACS_Status .ne. %loc(ACS_success) ) Then
C.....If ACS goal Value not available, don't execute
      Block_status(Block) = 'On-Err-ACS goal get'
      Return
15
End If
C
C...Target is Vantage variable
C
Else If ( Manip_var_system .eq.
20      Vantage_variable ) Then
      Van_Status = Gateuval ( Manip_var_number ,
1           Current_manipulated_value )
      If ( Van_Status .ne. %loc(van_success) ) Then
C..... If Variable Value not available, don't execute
      Block_status(Block) = 'On-Err-Vant var get '
      Return
25
End If
C
C...Target is Texas Instruments PM550 controller setpoint in CRD
C
Else If ( ( Manip_var_system .ge. Low_PM550 ) .and.
30      ( Manip_var_system .le. Hi_PM550 ) ) Then
C
35      If ( Manip_var_system .eq. CRD_ESCHS_PM550_01 ) Then
          ACS_status = TI_get_loop_setpoint ( 'TI_PM550_01_PORT' ,
1          Manip_var_number , Current_manipulated_value )
      Else If ( Manip_var_system .eq. CRD_ESCHS_PM550_02 ) Then
40          ACS_status = TI_get_loop_setpoint ( 'TI_PM550_02_PORT' ,
1          Manip_var_number , Current_manipulated_value )
      Else If ( Manip_var_system .eq. CRD_ESCHS_PM550_03 ) Then
45          ACS_status = TI_get_loop_setpoint ( 'TI_PM550_03_PORT' ,
1          Manip_var_number , Current_manipulated_value )
      Else If ( Manip_var_system .eq. CRD_ESCHS_PM550_04 ) Then
          ACS_status = TI_get_loop_setpoint ( 'TI_PM550_04_PORT' ,
1          Manip_var_number , Current_manipulated_value )
      Else If ( Manip_var_system .eq. CRD_ESCHS_PM550_05 ) Then
50          ACS_status = TI_get_loop_setpoint ( 'TI_PM550_05_PORT' ,
1          Manip_var_number , Current_manipulated_value )
      Else If ( Manip_var_system .eq. CRD_ESCHS_PM550_06 ) Then
          ACS_status = TI_get_loop_setpoint ( 'TI_PM550_06_PORT' ,
1          Manip_var_number , Current_manipulated_value )
      Else If ( Manip_var_system .eq. CRD_ESCHS_PM550_07 ) Then
65

```

```

      ACS_Status = TI_get_loop_setpoint ( 'TI_PH550_07_PORT' ,
5      Manip_var_number , Current_manipulated_value )
      End If
      If ( ACS_Status .ne. %loc(TI_success) ) Then
C.....If PH550 setpoint value not available, don't execute
      Block_Status(Block) = 'On-Err-TI setpnt get'
      Write( 6, *)
      10     ' Feedback exit - TI PH550 Manip var not gettable.'
      Write( 6, *) ' ACS Block: ',block,' at: ',now_time
      Return
      End If
      Else 1 Other Manip device type
      End If
15
C
C...Value is within limits - Test to see if the error is less than the deadband
C
      Error = Measured_value - Goal(Block)
      If ( Abs(Error) .lt. Absolute_deadband(Block) ) Then
20      d      Write( 6, *) 'Feedback error less than deadband'
      Return
      End If
C
C.....Compute proportional Feedback Response-Test Delta to see if too great
C
      Delta = Error * Proportional_gain(Block)
      If ( Abs(Delta) .gt. Max_manip_delta(Block) ) Then
          Delta = Sign(Max_manip_delta(Block),Delta)
      End If
30
C
C...Calculate new manipulated value, check to see if within limits
C
      New_manipulated_value = Current_manipulated_value + Delta
C
      If ( New_manipulated_value .gt. Manipulated_max(Block) ) Then
          New_manipulated_value = Manipulated_max(Block)
      Else If ( New_manipulated_value .lt. Manipulated_min(Block) ) Then
          New_manipulated_value = Manipulated_min(Block)
      End If
      Delta = New_manipulated_value - Current_manipulated_value
C
C... Transmit the new Manipulated Value to the manip variable
C
45
C...Target is TPA PCS loop goal
C
      If ( Manip_var_system .eq. PCS_TPA_Loop ) Then
          ACS_Status = ACS_put_pcs_goal( 'TPA
50          1      Manip_var_number , New_manipulated_value )
          If ( ACS_Status .ne. %loc(ACS_success) ) Then
C.....If PCS goal value not available, don't execute
          Block_Status(Block) = 'On-Err-PCS goal put'

```

```

      Write( 6, *) 'Feedback exit due to failed manip var put.'
      Write(6,*)' ACS Block: ',block,' at: ',now_time
      Return
5      End If

C
C...Target is DMT PCS loop goal
C

10     Else If ( Manip_var_system .eq. PCS_DMT_Loop ) Then
      ACS_Status = ACS_put_pcs_goal( 'DMT          ' ,
1      Manip_var_number , New_manipulated_value )
      If ( ACS_Status .ne. %loc(ACS_success) ) Then
C.....If PCS goal value not available, don't execute
15     Block_Status(Block) = 'On-Err-PCS goal put'
      Write( 6, *) 'Feedback exit due to failed manip var put.'
      Write(6,*)' ACS Block: ',block,' at: ',now_time
      Return
      End If

20     C
C...Target is ACS block goal
C

25     Else If ( Manip_var_system .eq. ACS_block ) Then
      ACS_Status = ACS_put_goal ( Manip_var_number ,
1      .          New_manipulated_value )
      If ( ACS_Status .ne. %loc(ACS_success) ) Then
C.....If ACS goal Value not available, don't execute
25     Block_Status(Block) = 'On-Err-ACS goal put'
      Write( 6, *) 'Feedback exit due to failed manip var put.'
      Write(6,*)' ACS Block: ',block,' at: ',now_time
      Return
      End If

30     C
C...Target is Vantage variable
C

35     Else If ( Manip_var_system .eq.
1           Vantage_variable ) Then
      Van_Status = Putegen ( Manip_var_number ,
1           New_manipulated_value )
      If ( Van_Status .ne. %loc(vsa_success) ) Then
C..... If Variable Value not available, don't execute
35     Block_Status(Block) = 'On-Err-Vant var put '
      Write( 6, *) 'Feedback exit due to failed manip var put.'
      Write(6,*)' ACS Block: ',block,' at: ',now_time
      Return
      End If

40     C
C...Target is Texas Instruments PM550 controller setpoint in CRD
C

45     Else If ( ( Manip_var_system .ge. Low_PM550 ) .and.
1           ( Manip_var_system .le. Hi_PM550 ) ) Then
C
50     If ( Manip_var_system .eq. CRD_ESCHS_PM550_01 ) Then

```

```

      ACS_Status = TI_put_loop_setpoint ( 'TI_PH550_01_PORT' ,
5      Manip_var_number , New_manipulated_value )
      Else If ( Manip_var_system .eq. CRD_ESCHS_PH550_02 ) Then
      ACS_Status = TI_put_loop_setpoint ( 'TI_PH550_02_PORT' ,
      Manip_var_number , New_manipulated_value )
      Else If ( Manip_var_system .eq. CRD_ESCHS_PH550_03 ) Then
      ACS_Status = TI_put_loop_setpoint ( 'TI_PH550_03_PORT' ,
10     Manip_var_number , New_manipulated_value )
      Else If ( Manip_var_system .eq. CRD_ESCHS_PH550_04 ) Then
      ACS_Status = TI_put_loop_setpoint ( 'TI_PH550_04_PORT' ,
      Manip_var_number , New_manipulated_value )
      Else If ( Manip_var_system .eq. CRD_ESCHS_PH550_05 ) Then
      ACS_Status = TI_put_loop_setpoint ( 'TI_PH550_05_PORT' ,
15     Manip_var_number , New_manipulated_value )
      Else If ( Manip_var_system .eq. CRD_ESCHS_PH550_06 ) Then
      ACS_Status = TI_put_loop_setpoint ( 'TI_PH550_06_PORT' ,
      Manip_var_number , New_manipulated_value )
      Else If ( Manip_var_system .eq. CRD_ESCHS_PH550_07 ) Then
      ACS_Status = TI_put_loop_setpoint ( 'TI_PH550_07_PORT' ,
20     Manip_var_number , New_manipulated_value )
      End If
      If ( ( ACS_Status .ne. %loc(TI_success) .and.
25     ( ACS_Status .ne. %loc(TI_clamped) ) ) Then
C.....If PM550 setpoint value not accessible, dont execute
      Block_Status(Block) = 'On-Err-TI setpnt put'
      Write( 6, *) 'Feedback exit - TI PH550 Manip var not puttable.'
      Write( 6, *) 'ACS Block: ',block,' at: ',now_time
      Return
      End If
      Else ! Other manip device types
      End If
35
C
C....Load special arrays for user programs to log messages.
C
      User_integer(1) = Measured_time_stamp
      User_integer(2) = Integer_now
      User_real(1)    = Delta
      User_real(2)    = Error
      User_character(1) = 'Feedback'
C
C...If Delta is non-zero, update past actions
C
      If ( Delta .ne. 0 ) Then
        Do 90 J = 5,2,-1
          Past_action_value(Block,J) = Past_action_value(Block,J-1)
40        Past_action_time (Block,J) = Past_action_time (Block,J-1)
        Past_action_value(Block,1) = Delta
        Past_action_time (Block,1) = Integer_now
      End If
C
C....Call User subprograms for this block
55

```

```

5          C
          Call User_programs(Block)
C
C...All done
C
10         Return
          End

```

### Feed forward Block

15 [0203] Figure 11 shows a sample of a template B12 presented to the user by the build-supervisor procedure to define a feed forward block. In the specific example shown, the block being worked on is block number six of the 200 available blocks 851, 852, etc., and the various data values shown in this Figure reflect the entries which have been made at some time to define this particular block.

20 [0204] The feedforward block provides proportional feedforward action. In feedforward action, the user specifies a measured value (called the "measured variable") and a manipulated variable whose value is to be changed in proportion to (or, more generally, in accordance with) the change in value of the measured variable. Feedforward action begins when the "old measured value" is set equal to a current value (usually when the block is first turned on). The measured variable is then monitored for changes in value and the manipulated variable value is changed in proportion. The "old measured value" is then updated to the value at the time of this action. (The use of the "old measured value" in feed-forward rules is one reason why an initialization stage is needed: if a feedforward block were switched from inactive status directly to on status, it might indicate a very large change to the manipulated variable if the delta were calculated from an out-of-date "old measured value.")

25 [0205] In the presently preferred embodiment, the basic feedforward action can be altered by several additional parameters. A deadband can be specified, so that, if the measured value changes by less than the deadband, no action is taken. The amount of action taken can be limited to a fixed amount. The range over which the value of the manipulated variable can be changed can be limited to keep it within operable limits. Screening limits can be specified on the measured variable value, so that measured values outside the screening limits are ignored. Block timing and switching options and the block description fields follow the general outlines given above.

30 [0206] In the presently preferred embodiment, specifying a feedforward block on the block setup selection form (Figure 9) brings up a feedforward block setup form like that shown in Figure 11.

### Parameters

40 [0207] The parameters are:

[0208] Measured variable type: a number code representing the software system and the type of entity which the block should use for the measured variable.

45 [0209] Measured variable number: the number of the entity within the specified system which the block will use for the measured variable. For example, if the measured variable type is a historical database variable, the measured variable number is the number of the variable in the historical database. After the measured variable type is entered, the label next to this field will show what type of data is needed. When the measured variable number is entered, other fields will also be filled in: the name and units for the measured variable, deadband; units and default values for the max and min measured values. If block timing to key off entry of new data into the measured variable, only discretely sampled variable types can be used.

50 [0210] Goal: the goal field cannot be used for feedforward blocks.

[0211] Manipulated variable type: a number code representing the software package and the type of entity which the block should manipulate. Examples are: control system loop goal, historical database variable.

55 [0212] Manipulated variable number: the number of the entity within the specified system which the block will manipulate. For example, if the manipulated variable type is a control system loop goal, the manipulated variable number would be the number of the loop whose goal is to be changed. The label next to this field will show what type of information is needed; in this case the label would show "Cont Sys loop #".

[0213] Proportional gain: the constant relating the change in the manipulated variable's value to the change in the measured variable's value. The units of the gain are shown to the right of the field after the measured and manipulated

variable have been specified. Control action is calculated as:

$$\text{Measured delta} = [\text{Measured variable value} - \text{Old value}]$$

5

$$\text{Manipulated delta} = \text{Measured delta} * [\text{Proportional gain}]$$

The manipulated delta is added (subject to limits) to the current value of the manipulated variable.

[0214] Deadband: A range around the "old measured value" (i.e. the measured value at the time of the last block action). If the value of the measured variable is within plus or minus the deadband of the old measured value, no action is taken and the old measured value is not changed.

[0215] Timing option, execution time interval, and Key block number: these parameters are described above.

[0216] Switch system and switch number: these are described above.

[0217] Maximum output delta: the maximum change that can be made in the manipulated variable's value in one control action.

[0218] Minimum and maximum value of the manipulated variable: limit values outside which control action will not move the value of the manipulated variable. If a computer control action would put the manipulated value outside the limits, the value is set equal to the limit. If the manipulated value is moved outside the limits (by operator action, for example) the next control action will return the value to within the limits.

[0219] Minimum and maximum value of measured variable: These define screening limits for reasonable values of the measured variable. Whenever the measured variable value falls outside these limits, the value will be ignored and no action is taken.

[0220] Action log file: this field is described above.

[0221] The use of a deadband in feedforward blocks is one of the features which tend to force process control into discrete steps, rather than continuous small changes. One advantage of this novel teaching is that full logging can be used: every single change made by the supervisor procedure can be logged, without generating an excessive number of messages. This in turn means that monitoring, diagnosis, and analysis of processes (and of process control systems) becomes much easier.

30

### Block Operation

[0222] The sequence of actions performed by a feedforward block is:

- Get the current value of the measured variable (If not accessible, set status to "On-err..." and do no further actions);
- Test the value of the measured variable. If it falls outside the allowed range of values, set status to "On-msrd out of lims" and do no further actions.
- Compute the change in the value of the measured variable:

40

$$\text{Delta measured} = \text{Measured value} - \text{Old measured value}.$$

If the absolute value of the change is less than the deadband, do no further actions.

- Compute the change in the manipulated variable:

45

$$\text{Delta\_manip} = \text{Delta measured} * \text{Proportional gain}.$$

- Set "old measured value" equal to the current value of the measured variable.
- If block status is "On-deselected", do no further actions;
- Check the magnitude of the manipulated value delta. If greater than the maximum allowed delta, set magnitude equal to the maximum.
- Get the current value of the manipulated variable. If not accessible, set status to "On-err ...." and do no further actions.
- Compute the new value of the manipulated variable:

$$\text{New manip value} = \text{Current manip value} + \text{delta\_manip}.$$

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If the value is outside the max/min limits, set it equal to the nearest limit. If limited, recompute the delta using the limit.

- Change the manipulated variable value to the new value computed. If not accessible, change status to "On-err ... " and do no further actions.
- Load user array values for use by the user routine.
- If delta\_manip is not zero, update the past action values and times.
- Call the user routine.

### Data passed to the user routine

10 [0223] The feedforward block passes information about its actions to the user routine through the User\_vars common block. The use of this data is described in more detail in the chapter covering User routines. In the presently preferred embodiment, the data passed by the feedforward block includes:

- 15 User\_integer(1) - the time stamp of the measured variable;
- User\_integer(2) - the time the action was taken;
- User\_real(1) - the change in the value of the manip variable;
- User\_real(2) - the change in the value of the measured variable from the last time the "old measured value" was updated;
- User\_character(1) - = 'Feedforward'.

### Sample Source Code

20 [0224] The source code for the procedure which actually performs this function, in the presently preferred embodiment, is as follows.

25

30

35

40

45

50

55

Table 3

```

5      ****
C
C      FEEDFORWARD_BLOCK.FOR
C
10     C      Subroutine to do feedforward calculations on the Vax,
C      communicating directly with the target system.
C
C
15     C
C      ****
C
C      Subroutine Feedforward_block ( Block )
C
20     Include 'ACSS$includes:Block_parameters.inc/nolist'
Include 'ACSS$includes:Van_functions.inc/nolist'
Include 'ACSS$includes:User_vars.inc/nolist'
Include 'ACSS$includes:ACSstatus.inc/nolist'
25     Include 'ACSS$includes:ACSServ.inc'
Include 'Acs$includes:Tiserv.inc'
Include 'Acs$includes:Tlistatus.inc'
Include 'ACSS$includes:Manip_params.inc'
30     Include 'ACSS$includes:Meas_params.inc'
C
C      Integer*2      Manip_var_type
35     Integer*2      Manip_var_num
Integer*2      Meas_var_type
Integer*2      Meas_var_num
Integer*4      Block
Real*4      Measured_value
40     Real*4      Current_manipulated_value
Real*4      New_manipulated_value
Integer*4      Integer_Now
Character*20   Character_now
Integer*4      Measured_time_stamp
45     C
C      Van_status = Vss$_from_ascii_time( ' ', Integer_now )
Van_status = Vss$_to_ascii_time( Integer_now , Character_now )
C
50     C...Get the measured value

```

```

5      C
6          ACS_Status = ACS_get_meas_var_type ( Block , Meas_var_type )
7          ACS_Status = ACS_get_meas_var_num ( Block , Meas_var_num )
8          Measured_time_stamp = 0
9
10     C
11     C...Measured Value  is TPA PCS loop goal
12     C
13         If ( Meas_var_type .eq. PCS_TPA_Loop_goal ) Then
14             ACS_Status = ACS_get_pcs_goal( 'TPA      ' ,
15                 1      Meas_var_num , Measured_value )
16             If ( ACS_Status .ne. %loc(ACS_success) ) Then
17                 C.....If PCS goal value not available, don't execute
18                     Block_Status(Block) = 'On-Err-PCS goal get'
19                     Write( 6, *) 'Feedback exit due to measured var not available'
20                     write(6,*)" ACS Block: ',block,' at: ',Character_now
21                     Return
22                 End If
23
24     C
25     C...Measured Value  is DNT PCS loop goal
26     C
27         Else If ( Meas_var_type .eq. PCS_DNT_Loop_goal ) Then
28             ACS_Status = ACS_get_pcs_goal( 'DNT      ' ,
29                 1      Meas_var_num , Measured_value )
30             If ( ACS_Status .ne. %loc(ACS_success) ) Then
31                 C.....If PCS goal value not available, don't execute
32                     Block_Status(Block) = 'On-Err-PCS goal get'
33                     Write( 6, *) 'Feedback exit due to measured var not available'
34                     write(6,*)" ACS Block: ',block,' at: ',Character_now
35                     Return
36                 End If
37
38     C
39     C...Measured Value  is ACS block goal
40     C
41         Else If ( Meas_var_type .eq. ACS_block_goal ) Then
42             ACS_Status = ACS_get_goal (
43                 1      Meas_var_num , Measured_value )
44             If ( ACS_Status .ne. %loc(ACS_success) ) Then
45                 C.....If ACS goal Value not available, don't execute
46                     Block_Status(Block) = 'On-Err-ACS goal get'
47                     Write( 6, *) 'Feedback exit due to measured var not available'
48                     write(6,*)" ACS Block: ',block,' at: ',Character_now
49                     Return
50                 End If
51
52     C
53     C...Measured Value  is Vantage variable
54     C
55         Else If ( Meas_var_type .eq. cur_val_Van_var ) Then
56             Van_Status = Vss$g_current( Meas_var_num ,
57                 1      Measured_value )
58             If ( Van_Status .ne. %loc(vss_normal) ) Then

```

```

C.....If Variable Value not available, don't execute
      Block_status(Block) = 'On-Failed Hard var'
      Write( 6, * ) 'Feedback exit due to measured var not available'
      write(6,*) 'ACS Block: ',block,' at: ',Character_now
      Return
  End If
  Ven_status = VenSg_curtim ( Meas_var_num ,
1                               Measured_time_stamp )
10
C
End If
C
C....Check the Measured variable to see if it is within limits
15
C
  If ( (Measured_value .lt. Measured_min(block) ) .or.
1     (Measured_value .gt. Measured_max(block) ) ) Then
C.....Reject the data point
  Return
20
End if
C
C...Test to see if the change in the measured value is less than the deadband
C
25
  Delta_meas = Measured_value - Old_measured_value(Block)
  If ( Abs( Delta_meas ) .lt.
1           Absolute_deadband(Block) ) Then
  Return
End If
30
C
C...Special action for 'On-deselected' status - update old_meas_value & C  exit.
C
35
  Old_measured_value(Block) = Measured_value
  If ( Block_status(Block)(1:13) .eq. 'On-deselected' ) Then
  Return
End If
C
C...Value is within limits - Compute Feedforward Response
40
C
  Delta_manip = Delta_meas * Proportional_gain(Block)
C
C...Test Delta_manip to see if too great
45
C
  If ( Abs(Delta_manip) .gt. Max_manip_delta(Block) ) Then
    Delta_manip = Sign(Max_manip_delta(Block),Delta_manip)
  End If
C
50
C...Get the current manipulated value
C
55
  ACS_status = ACS_get_manip_var_syst ( Block , Manip_var_type )
  ACS_status = ACS_get_manip_var_num ( Block , Manip_var_num )
C
C...Target is TPA PCS loop goal

```

```

C
5   If ( Manip_var_type .eq. PCS_TPA_Loop ) Then
      ACS_Status = ACS_get_pcs_goal( 'TPA      ' ,
1      Manip_var_num , Current_manipulated_value , )
      If ( ACS_Status .ne. %loc(ACS_success) ) Then
C.....If PCS goal value not available, don't execute
      Block_Status(Block) = 'On-Err-PCS goal get'
      Return
10   End If

C
C...Target is DMT PCS loop goal
C
15   Else If ( Manip_var_type .eq. PCS_DMT_Loop ) Then
      ACS_Status = ACS_get_pcs_goal( 'DMT      ' ,
1      Manip_var_num , Current_manipulated_value )
      If ( ACS_Status .ne. %loc(ACS_success) ) Then
C.....If PCS goal value not available, don't execute
      Block_Status(Block) = 'On-Err-PCS goal get'
      Return
20   End If

C
C...Target is ACS block goal
C
25   Else If ( Manip_var_type .eq. ACS_block ) Then
      ACS_Status = ACS_get_goal ( Manip_var_num ,
1                           Current_manipulated_value )
      If ( ACS_Status .ne. %loc(ACS_success) ) Then
C.....If ACS goal Value not available, don't execute
      Block_Status(Block) = 'On-Err-ACS goal get'
      Return
30   End If

C
C...Target is Vantage variable
C
35   Else If ( Manip_var_type .eq.
1                           Vantage_variable ) Then
      Van_Status = Geteval ( Manip_var_num ,
1                           Current_manipulated_value )
      If ( Van_Status .ne. %loc(vss_success) ) Then
40   C..... If Variable Value not available, don't execute
      Block_Status(Block) = 'On-Err-Vant var get'
      Return
45   End If

C
C...Target is Texas Instruments PM550 controller setpoint in CRD
C
50   Else If ( ( Manip_var_type .ge. Low_PM550 ) .and.
1           ( Manip_var_type .le. Hi_PM550 ) ) Then
55   C
      If ( Manip_var_type .eq. CRD_ESCHS_PM550_01 ) Then

```

```

      ACS_Status = TI_get_loop_setpoint ( 'TI_PM550_01_PORT' ,
5      Manip_Var_Num , Current_Manipulated_Value )
      Else If ( Manip_Var_Type .eq. CRD_ESCHS_PM550_02 ) Then
      ACS_Status = TI_get_loop_setpoint ( 'TI_PM550_02_PORT' ,
      Manip_Var_Num , Current_Manipulated_Value )
      Else If ( Manip_Var_Type .eq. CRD_ESCHS_PM550_03 ) Then
      ACS_Status = TI_get_loop_setpoint ( 'TI_PM550_03_PORT' ,
10     Manip_Var_Num , Current_Manipulated_Value )
      Else If ( Manip_Var_Type .eq. CRD_ESCHS_PM550_04 ) Then
      ACS_Status = TI_get_loop_setpoint ( 'TI_PM550_04_PORT' ,
      Manip_Var_Num , Current_Manipulated_Value )
      Else If ( Manip_Var_Type .eq. CRD_ESCHS_PM550_05 ) Then
      ACS_Status = TI_get_loop_setpoint ( 'TI_PM550_05_PORT' ,
15     Manip_Var_Num , Current_Manipulated_Value )
      Else If ( Manip_Var_Type .eq. CRD_ESCHS_PM550_06 ) Then
      ACS_Status = TI_get_loop_setpoint ( 'TI_PM550_06_PORT' ,
      Manip_Var_Num , Current_Manipulated_Value )
      Else If ( Manip_Var_Type .eq. CRD_ESCHS_PM550_07 ) Then
      ACS_Status = TI_get_loop_setpoint ( 'TI_PM550_07_PORT' ,
20     Manip_Var_Num , Current_Manipulated_Value )
      End If
      If ( ACS_Status .ne. %loc(TI_success) ) Then
C.....If PM550 setpoint value not available, don't execute
      Block_Status(Block) = 'On-Err-TI setpnt get'
      Write( 6, *)
      ' Feedforward exit - TI PM550 Manip Var not accessible.'
30      Write( 6, *) ' ACS Block: ',block,' at: ',now_time
      Return
      End If
      Else  ! Other Manip device type
      End If
C
C...Calculate new manipulated value, check to see it within limits
C
40      New_Manipulated_Value = Current_Manipulated_Value + Delta_Manip
C
      If ( New_Manipulated_Value .gt. Manipulated_Max(Block) ) Then
      New_Manipulated_Value = Manipulated_Max(Block)
      Else If ( New_Manipulated_Value .lt. Manipulated_Min(Block) ) Then
      New_Manipulated_Value = Manipulated_Min(Block)
45      End If
      Delta_Manip = New_Manipulated_Value - Current_Manipulated_Value
C
C... Transmit the New Manipulated Value to the manipulated variable
C
50      C...Target is TPA PCS loop goal
C
      If ( Manip_Var_Type .eq. PCS_TPA_Loop ) Then
      ACS_Status = ACS_Put_PCS_Goal( 'TPA
55

```

```

1      Manip_var_num , New_manipulated_value )
5      If ( ACS_Status .ne. %loc(ACS_success) ) Then
C.....If PCS goal value not available, don't execute
      Block_Status(Block) = 'On-Err-PCS goal put'
      Write( 6, *) 'Feedback exit due to failed manip var put.'
      Write(6,*)" ACS Block: ',block,' at: ',now_time
      Return
10     End If

C
C...Target is DMT PCS loop goal
C
15     Else If ( Manip_var_type .eq. PCS_DMT_Loop ) Then
      ACS_Status = ACS_put_PCS_goal( 'DMT
      1      Manip_var_num , New_manipulated_value )
      If ( ACS_Status .ne. %loc(ACS_success) ) Then
C.....If PCS goal value not available, don't execute
      Block_Status(Block) = 'On-Err-PCS goal put'
      Write( 6, *) 'Feedback exit due to failed manip var put.'
      Write(6,*)" ACS Block: ',block,' at: ',now_time
      Return
20     End If

C
C...Target is ACS block goal
C
25     Else If ( Manip_var_type .eq. ACS_block ) Then
      ACS_Status = ACS_put_goal ( Manip_var_num ,
      30           New_manipulated_value )
      If ( ACS_Status .ne. %loc(ACS_success) ) Then
C.....If ACS goal Value not available, don't execute
      Block_Status(Block) = 'On-Err-ACS goal put'
      Write( 6, *) 'Feedback exit due to failed manip var put.'
      Write(6,*)" ACS Block: ',block,' at: ',now_time
      Return
35     End If

C
C...Target is Vantage variable
C
40     Else If ( Manip_var_type .eq.
      45           Vantage_variable ) Then
      Van_Status = Putvugen ( Manip_var_num ,
      50           New_manipulated_value )
      If ( Van_Status .ne. %loc(vas_success) ) Then
C..... If Variable Value not available, don't execute
      Block_Status(Block) = 'On-Err-Vant var put'
      Write( 6, *) 'Feedback exit due to failed manip var put.'
      Write(6,*)" ACS Block: ',block,' at: ',now_time
      Return
55     End If

C
C...Target is Texas Instruments PM550 controller setpoint in CRD

```

```

C
5      Else If ( ( Manip_var_type .ge. Low_PM550 ) .and.
      |           ( Manip_var_type .le. Hi_PM550 ) ) Then
C
10     If ( Manip_var_type .eq. CRD_ESCHS_PM550_01 ) Then
      |     ACS_status = TI_put_loop_setpoint ( 'TI_PM550_01_PORT' ,
      |     Manip_var_num , New_manipulated_value )
15     Else If ( Manip_var_type .eq. CRD_ESCHS_PM550_02 ) Then
      |     ACS_status = TI_put_loop_setpoint ( 'TI_PM550_02_PORT' ,
      |     Manip_var_num , New_manipulated_value )
      |     Else If ( Manip_var_type .eq. CRD_ESCHS_PM550_03 ) Then
      |       ACS_status = TI_put_loop_setpoint ( 'TI_PM550_03_PORT' ,
      |     Manip_var_num , New_manipulated_value )
20     Else If ( Manip_var_type .eq. CRD_ESCHS_PM550_04 ) Then
      |       ACS_status = TI_put_loop_setpoint ( 'TI_PM550_04_PORT' ,
      |     Manip_var_num , New_manipulated_value )
      |     Else If ( Manip_var_type .eq. CRD_ESCHS_PM550_05 ) Then
      |       ACS_status = TI_put_loop_setpoint ( 'TI_PM550_05_PORT' ,
      |     Manip_var_num , New_manipulated_value )
25     Else If ( Manip_var_type .eq. CRD_ESCHS_PM550_06 ) Then
      |       ACS_status = TI_put_loop_setpoint ( 'TI_PM550_06_PORT' ,
      |     Manip_var_num , New_manipulated_value )
      |     Else If ( Manip_var_type .eq. CRD_ESCHS_PM550_07 ) Then
      |       ACS_status = TI_put_loop_setpoint ( 'TI_PM550_07_PORT' ,
      |     Manip_var_num , New_manipulated_value )
      |     End If
30     If ( ACS_Status .ne. %loc(TI_success) ) Then
C.....if PM550 setpoint value not available, don't execute
      |     Block_status(Block) = 'On-Err-TI setpnt put'
      |     Write( 6, * )
35     |     ' Feedforward exit - TI PM550 Manip var not puttable.'
      |     Write( 6, * ) ' ACS Block: ',block,' at: ',now_time
      |     Return
      |   End If
40   Else  | Other Manip device type
      |   End If
C
C....Load special arrays for user programs to log messages.
C
45     User_integer(1)  = Measured_time_stamp
     User_integer(2)  = Integer_now
     User_real(1)     = Delta_manip
     User_real(2)     = Delta_meas
     User_character(1) = 'Feedforward'
C
50     C...If Delta is non-zero, update past actions
C
55     If ( Delta_manip .ne. 0 ) Then
       Do 90  J = 5,2,-1
         Past_action_value(Block,J) = Past_action_value(Block,J-1)

```

```

90      Past_action_time (Block,J) = Past_action_time (
5      Past_action_value(Block,1) = Delta_manip
      Past_action_time (Block,1) = Integer_now
      End If

C
C....Call User subprograms for this block
C
10     Call User_programs(Block)
      Return
      End

```

15 Statistical Filtering Blocks

[0225] Figure 12 shows a sample of a template 812 presented to the user by the build-supervisor procedure to define a statistical filtering block. In the specific example shown, the block being worked on is block number one of the 200 available blocks 851, 852, etc., and the various data values shown in this Figure reflect the entries which have been made at some time to define this particular block.

[0226] The Shewhart block provides statistical filtering of a sampled measurement using Shewhart tests. The user specifies an aim value (field 1222 in Figure 12) and a standard deviation (sigma) (field 1224 in Figure 12) which characterizes the normal variability in the measurement. The Shewhart tests a series of rules to determine whether the sequence of measurements are statistically the same as ("on aim") or different from ("off aim") the normal variability with the average at the aim. After each test, the Shewhart block stores in the process database an estimate of the deviation from aim and a value indicating what rule was broken.

[0227] In the presently preferred embodiment, Shewhart blocks do not allow timing options to be specified. They perform their tests only when a new measurement is entered into the database for the filtered variable. In the presently preferred embodiment, the conditions tested for by the Shewhart block are:

30           Was the last point more than 3 sigma different from aim?  
               Were two of the last three points more than 2 sigma different from aim in the same direction?

[0228] Were four of the last five points more than 1 sigma different from aim in the same direction?

[0229] Were the last seven points all off aim on the same side of aim?

[0230] The rules are tested in the order shown. For the second and third rules, the test is first applied to the last two (or four) points in a row, then to the last three (or five) points. If any rule is violated, the process is off aim, and a deviation from aim is calculated by averaging the points which broke the rule. For example, if the last four points were outside the 1 sigma limit, the average of the four is taken as the deviation. If four of the last five points were outside the 1 sigma limits, the average of the last five points is taken.

[0231] The basic Shewhart action can be altered by several additional parameters. A fix time interval can be specified (in field 1226), so that, if one of the Shewhart tests shows a rule violation, Shewhart tests will be suspended for this interval after the time of the sample that violated the rule. This is useful in process control to allow control action in response to a rule violation to have time to move the process back to a statistically "on aim" position before taking any further actions. The range of calculated deviations can be limited, as specified by the data entered into fields 1228 and 1230. Screening limits can be applied to the filtered variable, so that measurements falling outside the range defined in fields 1232 and 1234 are ignored.

[0232] The Shewhart block differs from the feedback and feedforward blocks in that it requires resources outside of the supervisor procedure. It uses two process database variables to store its computed deviation from aim and its rule value. To configure a Shewhart block, in this sample embodiment, the user must get database variables allocated and properly configured. Since this is usually a database system manager's function, the details are not covered here.

[0233] Specifying a "Shewhart" (i.e. statistical filtering) block on the block setup selection form (Figure 9) brings up the Shewhart block setup form shown in Figure 12.

55 Parameters

[0234] The parameters shown on this form include:  
[0235] Filtered variable type: a number code representing the software system and the type of entity which the block

should use for the filtered variable.

[0236] Filtered variable number: the number of the entity within the specified system which the block will use for the filtered variable. For example, if the filtered variable type is a historical database variable, the filtered variable number is the number of the variable in the historical database. After the filtered variable type is entered, the label next to this field will show what type of data is needed. When the filtered variable number is entered, other fields will also be filled in: the name and units for the filtered variable, aim, and sigma; units and default values for the max and min filtered values. Since Shewhart block timing always keys off entry of new data into the filtered variable, only discretely sampled variable types can be used.

[0237] Deviation variable type: a number code representing the software system and the type of entity into which the block should store the computed value of deviation from aim.

[0238] Deviation variable number: the number of the entity within the specified system into the block will store the computed deviation from aim. For example, if the deviation variable type is a historical database variable, the deviation variable number is the number of the variable in the historical database. After the deviation variable type is entered, the label next to this field will show what type of data is needed. When the deviation variable number is entered, other information will be automatically filled in by the build-supervisor procedure; in the example of Figure 12, region 1236 indicates the pre-stored designation of historical database variable 2084. Such automatically completed information will preferably include the name and units for the deviation variable; units and default values for the max and min deviation values. Since Shewhart blocks execute on entry of new data into the filtered variable, only discretely stored deviation variable types can be used.

[0239] Rule variable type: a number code representing the software system and the type of entity into which the block should store a number code indicating which rule was broken.

[0240] Rule variable number: the number of the entity within the specified system into the block will store a number code indicating which rule was broken. For example, if the rule variable type is a historical database variable, the rule variable number is the number of the variable in the historical database. After the rule variable type is entered, the label next to this field will show what type of data is needed. When the rule variable number is entered, the name and units for the rule variable will also be filled in. Since Shewhart blocks execute on entry of new data into the filtered variable, only discretely stored rule variable types can be used.

[0241] Aim: the "on aim" value of the filtered variable.

[0242] Sigma: the standard deviation of the value of the filtered variable when the measurement is "on aim".

[0243] Fix time: A time interval after rule violations during which no rule tests are done. New measurements entered during the fix time interval are ignored. The fix time is entered as a delta time character string: "ddd hh:mm:ss" where "ddd" is the number of days, "hh" is the number of hours, "mm" is the number of minutes, and "ss" is the number of seconds. The fix time is taken from the timestamp of the filtered variable value which caused the deviation to be identified. The timestamp of later samples is compared against this, and if the difference is less than the fix time interval the sample is ignored.

[0244] Switch system and switch number: these are described above.

[0245] Minimum and maximum value of the calculated deviation: limits on the allowed value of the calculated deviation from aim. Deviations outside this range are set equal to the closest limit.

[0246] Minimum and maximum value of filtered variable: Screening limits for reasonable values of the filtered variable.

[0247] Action log file: this field is described above.

#### Block Operation

[0248] In the presently preferred embodiment, the sequence of actions performed by the Shewhart block is:

- If the block status is "On-deselected", do no further calculations.
- Retrieve the last 7 values of the filtered variable. If not available, do no further calculations.
- Check the last value of the filtered variable. If it is outside the allowed limits, do no further calculations.
- Search backward through the stored values of the deviation variable for the most recent non-zero value. If a non-zero value is found within one fix time interval before the present instant, do no further calculations.
- Compute the cutoff time = time of last non-zero deviation plus the fix time.
- Initialize the deviation and rule values (to zero).
- Begin testing Shewhart rules:
  - \* If the last point is older than the cutoff time, do no further calculations.
  - \* If the last point is outside the 3 sigma limits (i.e.  $Abs(point-aim)$  is greater than 3 sigma), then:

# EP 0 335 957 B1

Deviation = Last point - aim

5 Rule = 1

Skip remaining rules.

- \* If the second newest point is older than the cutoff time, Skip remaining rules.
- \* If the last 2 points are both either greater than aim + 2 sigma or less than aim

10 - 2 sigma, then:

Deviation = Sum(last 2 points)/2 - Aim

15 Rule = 3

Skip remaining rules.

- \* If 2 out of the last 3 points are both either greater than aim + 2 sigma or less than aim - 2 sigma, then:

20

Deviation = Sum(last 3 points)/3 - Aim

25 Rule = 3

Skip remaining rules.

- \* If the last 4 points are all either greater than aim + sigma or less than aim - sigma, then:

Deviation = Sum(last 4 points)/4 - Aim

30 Rule = 5

Skip remaining rules.

- \* If 4 of the last 5 points are all either greater than aim + sigma or less than aim - sigma, then:

35

Deviation = Sum(last 5 points)/5 - Aim

40 Rule = 5

Skip remaining rules.

- \* If all of the last 7 points are greater than aim or all less than aim, then:

45

Deviation = Sum(last 7 point)/7 - Aim

50 Rule = 7

Skip remaining rules.

- Check and store result:

- \* If the deviation is outside the allowable limits, set equal to the closest limit.
- \* Store the deviation value and rule value in the respective variables. These values are time stamped the same as the last filtered value.
- If the deviation is non-zero, update past actions.
- Call the user routine.

55

[0249] Of course, other statistical filtering methods could be used instead. It is generally realized that statistical filtering is highly advantageous, and that numerous algorithms can be used to accomplish statistical filtering. The Shewhart algorithm used in the presently preferred embodiment could be replaced by any of a wide variety of other known

algorithms.

Sample Source Code

5 [0250] The source code for the procedure which actually performs this function, in the presently preferred embodiment, is as follows.

Table 4

```

10
*****
C
C      Shewhart_block.for
15
C
C
*****
C
20      Subroutine Shewhart_block ( Block)
C
Include 'ACSS$includes:Block_parameters.inc/nolist'
Include 'acs$includes:ACSaerv.inc/nolist'
Include 'acs$includes:ACSstatus.inc/nolist'
Include 'ACSS$includes:Var_functions.inc/nolist'
Include 'ACSS$includes:Filter_params.inc/nolist'
Include 'ACSS$includes:dev_params.inc/nolist'
Include 'ACSS$includes:rule_params.inc/nolist'
Include 'ACSS$includes:User_vars.inc'

35      Integer*4      Block

40

45

50

55

```

```

5
      Integer      Error_lun
      Parameter    ( Error_lun = 6 )
      Character*20 Store_time
      Character*20 now_time

10
      C
      Integer*2    Filtered_variable
      Integer*2    Deviation_variable
      Integer*2    Rule_variable
      Integer*2    Filtered_variable_type
      Integer*2    Deviation_variable_type
      Integer*2    Rule_variable_type
      Integer*4    I4_deviation_variable
      Integer*4    I4_rule_variable
      Real*4      Aim
      Real*4      Sigma
      Integer*4   Integer_fix_time
      Integer*4   Cutoff_time
      Integer*4   Safe_time
      Real*4      Deviation
      Real*4      Rule
      Real*4      Last_filtered_value
      Logical     All_same_sign
      Logical     NeedViolation

25
      C
      Integer*4    Num_points
      Parameter    (Num_points = 7)
      Real*4      Point(Num_points)
      Integer*4    Times(Num_points)
      Character*18 Char_times(Num_points)
      Integer*4    Num_points1
      Parameter    (Num_points1 = 8)
      Real*4      Point1(Num_points1)
      Integer*4    Times1(Num_points1)
      Character*18 Char_times1(Num_points1)
      Real*4      Violation_value(1)
      Integer*4    Violation_time(1)
      Integer*4    Newest_time
      Integer*4    Oldest_time
      Integer*4    Buffer_size
      Logical*1   First_request
      Integer*4    Block_location
      Integer*4    Entry_count
      Integer*4    Begin_span_status
      Byte        Interp_flags
      Integer*4    Begin_span_time
      Integer*4    End_span_time
      Integer*4    Num_points_retrieved
      Integer*4    Integer_Now
      Integer*2    Start_point

40
      C
      C....Special case for 'On-deselected' status
      C

```

```

      If ( Block_status(Block)(1:13) .eq. 'On-deselected' ) Then
        Return
      End If
      5
      C..Set the value of the local variables
      C
        ACS_status = ACS_get_filtered_var_type(Block,filtered_variable_type)
        Filtered_variable = Measured_variable(Block)
        10
        ACS_status = ACS_get_dev_var_type ( Block , deviation_variable_type )
        Deviation_variable = Manipulated_variable(Block)
        ACS_status = ACS_get_rule_var_type ( Block , rule_variable_type )
        Rule_variable = New_manipulated_variable(Block)
        15
        Aim = Goal(Block)
        Sigma = Absolute_deadband(Block)
        Integer_fix_time = Fix_time(Block)
        C
          Van_status = Vss$_from_ascii_time ( ' ' , Integer_now )
        20
          Van_status = Vss$_to_ascii_time ( Integer_now , now_time )
        d  Van_status = Vss$_to_ascii_time ( Integer_now , Store_time )
        d  write(6,202) ' Calling Shewhart on var ',filtered_variable,' at ',
        d  1 Store_time
        d 202  format(1/,a,' ',f5,' ',a,' ',a)
        C
        C...Retrieve enough points to test all the rules
        C
          If ( Filtered_variable_type .eq. Van_var_filter ) Then
        30
          C
            Newest_time = Integer_now
            Oldest_time = Newest_time - 365*24*60*60
            Buffer_size = Num_points
            First_request = .True.
            35
            Num_points_retrieved = 0
            Start_point = 1
            C
              Do 777 j = 1,Num_points
              Times(j) = 0
        40
              777  Point(j) = 0.0
              C
                Van_status = Xloc(vss_systemdown)
                Do While ( (Van_status .eq. Xloc(vss_systemdown)) .or.
        45
                  1          (Van_status .eq. Xloc(vss_unavaildata)) )
                  C
                    Van_status = Vss$_Retrieve ( Filtered_variable , Newest_time ,
                    1          Oldest_time , Buffer_size , Times(start_point) ,
                    1          Point(Start_point) ,
                    1          First_request , Block_location , Entry_count ,
                    1          Begin_span_status , Interp_flags , Begin_span_time ,
                    1          End_span_time )
                    Num_points_retrieved = Num_points_retrieved + Entry_count
                    If ( Num_points_retrieved .lt. Num_points ) then
                      Buffer_size = Buffer_size - Num_points_retrieved
        50
                      Start_point = Start_point + Entry_count

```

```

      End If
d      write(6,*) 'Finished data retr.'
c
5      End Do
c
d      do 11 j =1,Num_points
d 11  Van_status = Vss$_to_ascii_time ( Times(j) , Char_times(j))
d      write(6,12) (Char_times(j),Point(j),j=1,num_points)
d 12  Format( /,' Here are the times and points:',// 
d      1      (' ',a18,' ',f12.4 , /) )
d      write(6,*) ' Got ',Num_points_retrieved,' points.'
If ( Num_points_retrieved .lt. Num_points ) then
      Write(Error_lun,*)
1 'Shewhart Failed to get enough data on Variable ',
1      Filtered_variable
      write(error_lun,*)'from ACS block:',block,' at:',now_time
      Write(Error_lun,*) 'Wanted ',Num_points,'; Got ',
1      Num_points_retrieved
      Return
End If
d      write(6,*) 'Got enough points.'
c
c
25      ....Check the Measured variable to see if it is within limits
c
      Last_filtered_value = Point(1)
      If ( (Last_filtered_value .lt. Measured_min(block) ) .or.
1      (Last_filtered_value .gt. Measured_max(block) ) ) Then
c.....Reject the data point
      Write( 6, * ) 'Shewhart exit due to out of limts filtered.'
      write(6,*)' ACS Block: ',block,' at: ',now_time
      Return
      End If
      Else if ( Filtered_variable_type .eq. Van_run_2_filter ) Then
c
40      Newest_time = Integer_now
      Oldest_time = Newest_time - 365*24*60*60
      Buffer_size = Num_points1
      First_request = .True.
      Num_points_retrieved = 0
      Start_point = 1
c
45      Do 1777 j = 1,Num_points1
      Times1(j) = 0
      1777 Point1(j) = 0.0
c
50      Van_status = %loc(vss_systemdown)
      Do While ( (Van_status .eq. %loc(vss_systemdown)) .or.
1      (Van_status .eq. %loc(vss_unavaildata)) )
c
55      Van_status = Vss$_Retrieve ( Filtered_variable , Newest_time ,
1      Oldest_time , Buffer_size , Times1(start_point) ,

```

```

5          Point1(Start_point) ,
5          First_request , Block_location , Entry_count ,
5          Begin_span_status , Interp_flags , Begin_span_time ,
5          End_span_time )
5          Num_points_retrieved = Num_points_retrieved + Entry_count
5          If ( Num_points_retrieved .lt. Num_points1 ) then
5              Buffer_size = Buffer_size - Num_points_retrieved
5              Start_point = Start_point + Entry_count
5          End If
10         write(6,*) 'Finished data retr.'
11
12         End Do
13
14         do 111 j =1,Num_points1
15         Var_status = Vss$_to_ascii_time ( Times1(j) , Char_times1(j) )
16         write(6,112) (Char_times1(j),Point1(j),j=1,num_points1)
17         112 Format( /, '  Here are the times and points:',//,
18             1      (' ',a18,' ',f12.4 , / ) )
19         write(6,*) ' Got ',Num_points_retrieved,' points.'
20         If ( Num_points_retrieved .lt. Num_points1 ) then
21             Write(Error_lun,*)
22             1 'Shewhart Failed to get enough data on Variable ',
23             1      Filtered_variable
24             write(error_lun,*) 'from ACS block:',block,' at:',now_time
25             Write(Error_lun,*)
26             1 'Wanted ',Num_points1,'; Got ',
27             1      Num_points_retrieved
28             Return
29
30         End If
31         write(6,*) 'Got enough points.'
32
33         C....Check the Measured variable to see if it is within limits
34
35         Last_filtered_value = (Point1(1)+Point1(2))/2.
36         If ( (Last_filtered_value .lt. Measured_min(block) ) .or.
37             1      (Last_filtered_value .gt. Measured_max(block) ) ) Then
38             C....Reject the data point
39             Write( 6, * ) 'Shewhart exit due to out of limts filtered.'
40             write(6,*) ' ACS Block: ',block,' at: ',now_time
41             Return
42         End If
43
44         Do j = 1,num_points
45             point(j) = (point1(j)+point1(j+1))/2
46             times(j) = times1(j)
47         end do
48
49         Else 1 Improper filtered type
50             Write( 6, * ) 'Shewhart exit due to invalid filtered var type.'
51             write(6,*) ' ACS Block: ',block,' at: ',now_time
52             Return
53
54         End If 1 Filtered types

```

```

5
C
C....Check to see if the last violation was within the Fix time -
C    If so, do no calculations.
C
C...Retrieve the last stored nonzero deviation from aim
C
10    If ( Deviation_variable_type .eq. Van_var_dev ) Then
C
15        Newest_time = Integer_now
        Oldest_time = Newest_time - 365*24*60*60
        Buffer_size = 1
        First_request = .True.
        NeedViolation = .True.
        Do While ( NeedViolation )
C
20            Van_Status = Vss$Retrieve ( Deviation_variable , Newest_time ,
1            Oldest_time , Buffer_size , Violation_time ,
1            Violation_value ,
1            First_request , Block_location , Entry_count ,
1            Begin_Span_Status , Interp_flags , Begin_Span_time ,
1            End_Span_time )
C
25            If ( ( Van_Status .ne. %loc(vss_systemdown) ) .and.
1            ( Van_Status .ne. %loc(vss_unavaildata)) .and.
1            ( Van_Status .ne. %loc(vss_notallfound)) ) Then
C
30                Write(6,*)' Shewhart Violation retr - status vss_badvarnum'
                Write(6,*)' ACS Block: ',block,' at: ',now_time
C
35            Else If( Van_Status .eq. %loc(vss_badtime) ) then
                Write(6,*)' Shewhart Violation retr - status vss_badtime'
                Write(6,*)' ACS Block: ',block,' at: ',now_time
C
40            Else If( Van_Status .eq. %loc(vss_badtimespan) ) then
                Write(6,*)' Shewhart Violation retr - status vss_badtimespan'
                Write(6,*)' ACS Block: ',block,' at: ',now_time
C
45            Else If( Van_Status .eq. %loc(vss_badbufsize) ) then
                Write(6,*)' Shewhart Violation retr - status vss_badbufsize'
                Write(6,*)' ACS Block: ',block,' at: ',now_time
C
50            Else If( Van_Status .eq. %loc(vss_normal) ) then
                Write(6,*)' Shewhart Violation retr - status vss_normal'
                Write(6,*)' ACS Block: ',block,' at: ',now_time
C
55            Else If( Van_Status .eq. %loc(vss_nonefound) ) then
                Write(6,*)' Shewhart Violation retr - status vss_nonefound'
                Write(6,*)' ACS Block: ',block,' at: ',now_time
C
60            Else If( Van_Status .eq. %loc(vss_nomoreonline) ) then
                Write(6,*)' Shewhart Violation retr - status vss_nomoreonline'
                Write(6,*)' ACS Block: ',block,' at: ',now_time
C
65

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        write(6,*)" ACS Block: ',block,' at: ',now_time
c
5      End If
      Write(6,*) ' Van_Status = ',Van_Status
      Van_Status = Vss$_to_ascii_time ( Violation_time(1) , Store_time )
      Write(Error_lun,*)
1      'Shewhart-couldn't get a non zero deviation - exiting'
      write(6,*)" ACS Block: ',block,' at: ',now_time
      Write(Error_lun,*)
1      ' Oldest violation got: ',Violation_value(1),' at ',Store_time
      Return
End If
15     If ( ( Abs(Violation_value(1)) .gt. 1.0 E-10 ) .or.
1      ( Violation_time(1) .lt.
1           (Times(7) - Abs( Integer_fix_time ))) ) Then
      NeedViolation = .False.
End If
20     c
      End Do
Else ! Improper deviation var type
      Write( 6, *) 'Shewhart exit due to invalid deviation var type.'
      write(6,*)" ACS Block: ',block,' at: ',now_time
      Return
End If ! Get last deviation for allowed deviation types
c
c
30     d      Van_Status = Vss$_to_ascii_time ( Violation_time(1) , Store_time )
d      write(6,*) ' Got a violation of ',Violation_value(1),' at ',
d      1
d           Store_time
c
C....Go through the shewhart Rules - any point older than the last violation
35     C      time + the fix time is not acceptable.
c
        Cutoff_time = Violation_time(1) + Abs(Integer_fix_time)
d      Van_Status = Vss$_to_ascii_time ( Cutoff_time , Store_time )
d      write(6,*) ' Cutoff time is ', Store_time
c
40     C      Deviation = 0.0
      Rule = 0.0
c
45     If ( Times(1) .lt. Cutoff_time ) Return
d      write(error_lun,*) 'Testing 1 out of 1 rule.'
      If ( Abs(Point(1)-Aim) .gt. 3*Sigma ) Then
          Deviation = Point(1) - Aim
          Rule = 1.0
          Go To 1000
      End If
c
C..Test 2 in a row outside 2 sigma
c
55     If ( Times(2) .lt. Cutoff_time ) Go To 1000
d      write(error_lun,*) 'Testing 2 out of 2 rule.'

```

```

5           Sum_points = 0.0
             Num_out_high = 0
             Num_out_low = 0
Do 2 J = 1,2
             Sum_points = Sum_points + Point(J)
             If ( (Point(J)-Aim) .gt. 2*Sigma ) Then
                 Num_out_high = Num_out_high +1
             Else If ( (Point(J)-Aim) .lt. -2*Sigma ) Then
                 Num_out_low = Num_out_low + 1
             End If
2           Continue
             If ( ( Num_out_high .eq. 2 ) .or.
15             ( Num_out_low .eq. 2 ) ) Then
                 Deviation = Sum_points/2 - Aim
                 Rule = 3.0
                 Go To 1000
             End If
20           C
             C...Test 2 out of 3 outside of 2 sigma
             C
             If ( Times(3) .lt. Cutoff_time ) Go To 1000
25             d           write(error_lun,*)
             Sum_points = Sum_points + Point(3)
             If ( (Point(3)-Aim) .gt. 2*Sigma ) Then
                 Num_out_high = Num_out_high +1
             Else If ( (Point(3)-Aim) .lt. -2*Sigma ) Then
                 Num_out_low = Num_out_low + 1
             End If
             If ( ( Num_out_high .eq. 2 ) .or.
50             ( Num_out_low .eq. 2 ) ) Then
                 Deviation = Sum_points/3 - Aim
                 Rule = 3.0
                 Go To 1000
             End If
             C
             C...Test 4 in a row outside 1 sigma
             C
             If ( Times(4) .lt. Cutoff_time ) Go To 1000
             d           write(error_lun,*)
             Sum_points = 0.0
             Num_out_high = 0
             Num_out_low = 0
Do 3 J = 1,4
             Sum_points = Sum_points + Point(J)
             If ( (Point(J)-Aim) .gt. 1*sigma ) Then
                 Num_out_high = Num_out_high +1
             Else If ( (Point(J)-Aim) .lt. -1*Sigma ) Then
                 Num_out_low = Num_out_low + 1
             End If
3           Continue
             If ( ( Num_out_high .eq. 4 ) .or.
55             ( Num_out_low .eq. 4 ) ) Then

```

```

      Deviation = Sum_points/4 - Aim
      Rule = 5.0
      Go To 1000
5      End If
      C
      C...Test 4 out of 5 outside 1 sigma
      C
      If ( Times(5) .lt. Cutoff_time ) Go To 1000
10     d     write(error_lun,*) 'Testing 4 out of 5 rule.'
      Sum_points = Sum_points + Point(5)
      If ( (Point(5)-Aim) .gt. 1*Sigma ) Then
          Num_out_high = Num_out_high +1
      Else If ( (Point(5)-Aim) .lt. -1*Sigma ) Then
          Num_out_low = Num_out_low + 1
      End If
      If ( ( Num_out_high .eq. 4 ) .or.
15     1   ( Num_out_low .eq. 4 ) ) Then
          Deviation = Sum_points/5 - Aim
          Rule = 5.0
          Go To 1000
20     End If
      C
      C...Test 7 in a row - same side of aim
      C
      If ( Times(7) .lt. Cutoff_time ) Go To 1000
25     d     write(error_lun,*) 'Testing 7 in a row rule.'
      Sum_points = 0.0
      Sign_deviation = Sign( 1.0,(Aim-Point(1)) )
30     If ( (Aim-Point(1)) .ne. 0 ) Then
          All_same_sign = .True.
      else
          All_same_sign = .False.
35     End If
      Do 4 J = 1,7
          If ( (Aim-Point(J)) .eq. 0 ) Then
              All_same_sign = .False.
          Else If ( Sign( 1.0,(Aim-Point(J)) ) .ne. Sign_deviation ) Then
              All_same_sign = .False.
40     End If
          4     Sum_points = Sum_points + Point(J)

45     If ( All_same_sign ) then
          Deviation = Sum_points/7 - Aim
          Rule = 7.0
          Go To 1000
      End If
50     C
      1000 Continue
      d     write(6,*) 'Got deviation, rule of ',deviation,rule
      C
      C...Clamp the deviation at allowed limits
55     C

```

```

      If ( Deviation .gt. Manipulated_max(Block) ) Then
          Deviation = Manipulated_max(Block)
      Else If ( Deviation .lt. Manipulated_min(Block) ) Then
          Deviation = Manipulated_min(Block)
      End If

      C
      C...Store the Computed Deviation and Rule number with Timestamp
      C
      d      Van_status = Van$_to_ascii_time ( Times(1) , store_time )
      d      write(6,*) 'putting var ',14_deviation_variable,' at ',store_time,
      d      ' with value ',deviation
      c

      15     If ( Deviation_variable_type .eq. Van_var_dav ) Then
          14_deviation_variable = Deviation_variable
          Dmt_status = Dmt$_putlab ( 14_deviation_variable , Times(1) ,
          1             Deviation , 2 , .False. )
      Else If Other deviation types
      End If ! Deviation types

      C
      d      write(6,*) ' Did putlabs -first status = ',dmt_status
      d      write(6,*) 'putting var ',14_rule_variable,' at ',store_time,
      d      ' with value ',rule
      c

      25     If ( Rule_variable_type .eq. Van_var_rule ) Then
          14_rule_variable = rule_variable
          Dmt_status = Dmt$_putlab ( 14_rule_variable , Times(1) ,
          1             Rule , 2 , .False. )
      Else If Other rule types
      End If ! Rule types

      C
      c      status = vms$_mehclose()           !close file just in case
      c

      d      write(6,*) ' Did putlabs -second status = ',dmt_status
      d      write(6,*) ' Did putlabs -exiting'
      c

      35     C...If Deviation is non-zero, update past actions
      C
          If ( Deviation .ne. 0 ) Then
              Do 90  J = 5,2,-1
                  Past_action_value(Block,J) = Past_action_value(Block,J-1)
              90      Past_action_time (Block,J) = Past_action_time (Block,J-1)
                  Past_action_value(Block,1) = Deviation
                  Past_action_time (Block,1) = Times(1)
              End If

      C
      C...Load user arrays for user programs
      C
          User_integer(1) = Integer_now  ! Time of Tests
          User_integer(2) = Rule
          User_real(1) = Deviation
          Do J = 1 , Max ( Num_points , 18 )
              User_integer(2+J) = Times(J)  ! Time of samples used in tests

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      User_real (2+j) = Point(j)  ! Value of samples used in test
  End Do
  5   If ( Rule .eq. 0.0 ) Then
      User_character(1) = 'On aim, No rules broken'
      User_character(2) = 'On aim, No rules broken.'
    Else If ( Rule .eq. 1.0 ) Then
      User_character(1) = 'Shewhart 1 out of 1 rule'
    10  User_character(2) = 'Shew heart 1 out of 1 rule'
    Else If ( Rule .eq. 3.0 ) Then
      User_character(1) = 'Shewhart 2 out of 3 rule'
      User_character(2) = 'Shew heart 2 out of 3 rule'
    15  Else If ( Rule .eq. 5.0 ) Then
      User_character(1) = 'Shewhart 4 out of 5 rule'
      User_character(2) = 'Shew heart 4 out of 5 rule'
    Else If ( Rule .eq. 7.0 ) Then
      User_character(1) = 'Shewhart 7 in a row rule'
      User_character(2) = 'Shew heart 7 in a row rule'
    20  End If
  C
  25  C...Call User routine
  C
      Call User_programs ( Block )
      Return
      End
  30

```

#### User-Defined Program Block

35 [0251] Figure 13 shows the form which (in the presently preferred embodiment) is presented to a user who has chosen the "User program" option from the menu shown in Figure 9.

[0252] The user program block provides a means of controlling the execution of a user written FORTRAN subroutine. The block itself performs no control actions, but allows the user to specify a timing option and switch parameters for executing the block's user routine. A user routine exists for every block in the supervisor procedure. (In the example shown in Figure 13, where the block shown is block number 2, the block will (selectively) make calls to BLOCK2\_USER\_ROUTINE.) Initially these routines (BLOCK1\_USER\_ROUTINE, BLOCK2\_USER\_ROUTINE, BLOCK3\_USER\_ROUTINE, etc.) do nothing (i.e., their default content is merely the FORTRAN statements Return and End), but they can be modified by the user. The user program block only sets up parameters for controlling execution of the user program.

40 [0253] The user program timing options include keying off a measured variable. In this case the variable is not used for anything but timing. This option can be altered by specifying screening limits on the measured variable value (using fields 1332 and 1334), so that measured values outside the screening limits are ignored. Block timing and switching and the block description fields follow the general outlines given above.

#### Parameters

50 [0254] The parameters are:

[0255] Measured variable type: a number code representing the software system and the type of entity which the block should use for the measured variable.

[0256] Measured variable number: the number of the entity within the specified system which the block will use for the measured variable. For example, if the measured variable type is a historical database variable, the measured variable number is the number of the variable in the historical database. After the measured variable type is entered, the label next to this field will show what type of data is needed. When the measured variable number is entered, other fields will also be filled in: the name and units for the measured variable; units and default values for the max and min

measured values.

[0257] Timing option, execution time interval, and Key block number: these parameters are described above.

[0258] Switch system and switch number: these are described above.

[0259] Minimum and maximum value of measured variable: These define screening limits for reasonable values of the measured variable. Whenever the measured variable value falls outside these limits, the value will be ignored and no action is taken.

[0260] Action log file: this field is described above.

#### Program Block Operation

[0261] The sequence of actions performed by a User program block is:

- If block status is "On-deselected", do not execute the user routine.
- If a measured variable is specified:
  - \* Get the current value of the measured variable (If not accessible, set status to "On-err..." and do not execute the user routine).
  - \* Test the value of the measured variable. If it outside the range of allowed values, set status to "On-msrd out of lims" and do not execute the user routine.
- Execute the user routine. The routine name is derived from the block number. Block 1 calls Block1\_user\_routine, block 199 calls Block-199\_user\_routine, etc.
- If a fatal error occurs in the user routine, bypass the rest of the routine, and set the block status to "On-Failed user routine".
- If the block failed on the last execution, but did not fail on this execution, set the block status to "On".
- Clear all the values in the user\_vars common block.

#### Build-User-Program Procedure

[0262] The build-supervisor procedure (in the presently preferred embodiment) also provides a structured environment for creating user programs. As will be described below, the build-expert procedure will create the source code for one or more customized expert systems; but the user must still insert a call to this expert code into one of the blocks in the supervisor procedure. The build-user-program procedure facilitates this, and also provides convenient support for sophisticated users who are able to write their own utilities.

[0263] In the presently preferred embodiment, this is a structured environment in which users can write FORTRAN subroutines and incorporate them into control blocks. User programs can be run as the only block function by defining a User Program block (as described above), or they can be used to take additional actions (such as message logging) in combination with feedback or feedforward control blocks.

[0264] At a minimum, a user with no programming knowledge can insert a one-line call into a user program block, to make use of an expert subprocedure created using the build-expert procedure. However, to take full advantage of the capability for user programming, the user should (in the presently preferred embodiment) already be comfortable programming in FORTRAN and using FORTRAN functions and subroutines, and in using the Vax EDT editor. The build-user-program environment 1810 in this embodiment is menu driven rather than forms driven, and therefore provides less online help than some of the other functions described.

[0265] Writing a basic user program involves 5 steps:

- Selecting which block number's user program to edit;
- Editing the file which contains the user program code for the block. The EDT editor 1812 is used to write and modify the FORTRAN language code;
- Checking the code for errors in FORTRAN syntax;
- Updating the supervisor procedure by incorporating the latest version of the user program into the base cycle procedure and running the new base cycle procedure; and
- Monitoring user program execution to assure that the program is executing properly.

[0266] In the example shown in Figure 16, the top level build-supervisor menu permits the user to enter the build-user-program environment by pressing keypad 5. While in the build-user-program environment, the user can edit the block user routine; check the block user routine for errors in FORTRAN syntax; and update the supervisor procedure

by incorporating the new version of the block user routine. The first prompt from the user program menu asks what block number's routine the user wants to work on. Entering the block number and pressing return brings up another program menu, with options which will now be described.

[0267] Editing the user routine begins by selecting menu option 1 ("Edit user routine"). This will start the EDT editor.

5 User routines of some sort already exist for all the blocks. Blocks which have never had any special programming have a user routine which does nothing - it consists simply of a RETURN statement followed by an END statement, and, if the block's user routine has never been worked on, this default routine will be brought up by the editor. To make a functioning routine, the user must add FORTRAN code before the RETURN statement to perform the desired function. (In the presently preferred embodiment, the user can simply edit the file like any other FORTRAN source code file on the VAX.) For example, code for logging messages or calling an expert subroutine can be inserted at this point.

10 [0268] Once the user has edited the user routine and returned to the menu, he can select option 5 to check for FORTRAN syntax errors. If the new routine has no FORTRAN syntax errors, the screen will show "The user's routine compiled with no errors in syntax." If the new coding has syntax errors, the user will see them reported on the terminal screen. The user can then correct the errors using Option 1 (edit), and repeat until all errors have been removed.

15 [0269] Once the user has a routine that compiles with no errors, he can include it in the running version of the supervisor procedure by using menu option B ("Update"). This will compile the user's routine, relink the base cycle procedure using the user's newly compiled routine, stop the procedure which is currently running, the restart the base cycle procedure using the newly linked version containing the user's new routine.

20 [0270] After compiling the user's routine, the build-supervisor procedure will ask if there are any other subroutines in separate files that need to be compiled. Some application may require more than one subroutine, and, if desired, they can be split up in separate files. To make a routine in a separate file, the user can select option 2 ("Edit a separate FORTRAN subroutine") to create and modify the file, and then select option 6 ("Check a separate subroutine for FORTRAN errors") to check for FORTRAN errors. To include the separate file into the supervisor procedure, the user can use the update option, then answer "Y:" when asked if any separate routines need to be compiled and included. The base cycle procedure can then be linked, and then restarted.

25 [0271] After the user's routine has been incorporated into the basic cycle procedure, the user can monitor it to make sure it executes properly. There are two key indicators of a problem with the user's user routine: the block status and the control program log file. If the user's routine has an error which would normally cause a stand-alone FORTRAN program to terminate, the base cycle procedure will bypass the error and the remainder of the user's routine, and change the block status to "On-Failed usr routin". This can be seen using the block monitoring screen. If the user's routine fails once but runs successfully on a subsequent execution, the block status will be changed to "On-Recoverd Usr Error", and a message will be posted in the control program log file indicating which user routine had the error, when it occurred, and what the error was. The log file can be viewed using the "List log file" option on the System functions screen.

30 [0272] The user can print a listing of a user routine by using option 3 (or option 4 for a separate routine).

35 [0273] If the user's user routine fails and the user needs to retreat to the last version that was running, he can use the restore option (keypad 9). This will prompt the user for any separate routines that need to be restored, and retrieve the old versions saved by the build-supervisor procedure.

40 [0274] In the presently preferred embodiment, there are several include files which can be used in user routines: "User\_vars.inc" contain a common block which is used to pass information about control block actions to user routines. The common block contains a Real array, an integer array, and a character\*80 array. Control blocks load values into these arrays for the amount of change made in the manipulated variable, the error in a feedback block, the time the action was taken, etc. The user program block zeros out these values after the user routine executes a RETURN statement. "ACSserv.inc" declares all the ACS service routines (which are integer\*4 functions). "ACSstatus.inc" declares all the legal ACS status return values. These values must be declared external before they can be used. "Van\_functions.inc" declares some of the retrieval and time functions from the historical process database, and declares some of the status return values.

45 [0275] Of course, many different computer languages and architectures could be used in practising the present invention: the sample FORTRAN routines specified (as well as other features which, for example, relate specifically to the use of a VMS operating system) simply sets forth the best mode as presently practiced, but a tremendous variety of other languages, operating environments, and/or hardware could be used instead.

#### Block-Handling Utilities

50 [0276] Figure 14 shows a menu which is preferably presented to a user who has elected to use the utilities provided in the build-supervisor procedure (e.g. by hitting keypad 9 when faced with the menu shown in Figure 16). While these utilities are not necessary parts of every implementation of the innovative concepts described in the present application, they do help users to take advantage of the full power available.

[0277] In the presently preferred embodiment, the supervisor procedure includes the capabilities for copying and deleting blocks, and for printing listings of block setup parameters. Deleting a block (Keypad 7) removes all the block type and setup parameter data for the block, leaving it available for another user. Copying a block (Keypad 8) reproduces the block type and setup parameters of one block into another. Printing blocks (Keypad 9) allow the user to select 5 blocks to be printed either by number range or by searching for string matches in the application name or block description fields, and makes full or abbreviated listings of block parameter data on the printer of the user's choice.

[0278] If the user elects to copy a block, the build-supervisor procedure prompts the user to enter in the "Source block" field 1402 the number of the block to copy. The build-supervisor procedure then fills in the information fields 10 appropriately for that block, allowing the user to confirm that he has entered the right block number, and prompts the user again for the target block into which the block should be copied (field 1404). After this is entered the build-supervisor procedure fills in the information fields for the target block, and prompts the user again. When the user confirms that the block is to be copied, the block type and parameters are overwritten in the shared memory 814. After the block is copied, the build-supervisor procedure prompts the user again, asking whether the source block should be deleted or left unchanged. The build-supervisor procedure confirms that the source block was either deleted or not deleted.

[0279] Block information can only be copied into target blocks whose status is "Off" or "Inactive". To copy information 15 into a block with an active status, the user must go to the block setup form for that block, and toggle and block off. This safeguard provides greater system integrity.

[0280] In the presently preferred embodiment, keypad 9 will initiate printing a listing of selected block parameters. The build-supervisor procedure will prompt the user to enter in field 1410 for the starting range of block numbers to 20 print, or to hit return if he wishes to select blocks by string searches. To print a range of block numbers, the user can enter the lowest number block in the range, press return, then enter the higher number block (in field 1412) and press return. To select the blocks to be printed by search for string matches, the user can press return without entering a number for the starting block. To search the block description fields, the user can enter the desired string in the description search string field 1406. To search the block application name field, the user can press return without entering 25 anything in the description field, and enter the desired string when prompted in the application name field 1408. In either case, the user can use capital and lower case letters interchangeably, since case is not checked in the string searches. The user need not fill in the whole search string field. A block will be selected to print if the string the user enters appears anywhere in the searched field.

[0281] The build-supervisor procedure will now prompt the user for a short or long list. A short list shows only the 30 block number, type, description, and application name. A long list shows the entire setup form for that block. The build-supervisor procedure will clear the screen and prompt the user for the printer he wishes to use. The user can type the number of the printer if he knows it, or enter L to get a list of printers to choose from. The user's terminal screen and its attached printer can be selected, as well as Vax system printers. When the print job is completed, the build-supervisor procedure will report the number of blocks that were printed.

35

#### Monitoring

[0282] In addition, the supervisor procedure provides several functions for following the performance of control strategies as they operate. The block monitoring screen allows the actions of individual blocks to be followed. The system 40 functions screen shows the status of the supervisor procedure. The control system runs as a batch-type process on the Vax, and so it has a log file which contains all the error messages generated by the system.

[0283] A user who requests block-monitoring is presented with a block description form which includes a block 45 number field in which he can insert the number of the block to be monitored. The remaining fields on the form then are filled in appropriately by the build-supervisor procedure, and are subsequently updated every 5 seconds. The information shown includes:

- the current time;
- the time at which the supervisor base cycle procedure will make its next scan through the blocks (and blocks which are due to execute will be executed);
- the block type (which was specified during block setup, e.g. feedforward, feedback, etc.);
- the block description (which was entered during setup);
- the type, number, name and units of the measured variable which was specified in block setup (if none was specified (e.g. in a program block), this field will be blank);
- the current value and time stamp of the measured variable (the time stamp for compressed variables in the time 55 the last new value was received; for manual entry variables it is the time stamp of the last entered value; and if no measured variable was specified, this field is blank);
- the goal value for feedback blocks (for other block types, this field is empty);
- the number, name, units and type of manipulated variable;

- the current value of the manipulated variable (with time stamp if one has been defined);
- the timing option entered during block setup;
- the execution time interval specified during block setup. If the block timing does not include any fixed frequency, this field is blank.

5    - the time the block last did its scheduled actions (this is normally the last time the block was scheduled to execute according to its timing option parameters, regardless of whether the block acted to change the manipulated variable);

- the current status of the block; and
- the last five control actions made by the block (or, for Shewhart blocks, the last five deviation values) and the time at which they occurred.

10

[0284] In the presently preferred embodiments, a similar overhead function permits the user to take a look at the current status of key system parameters, including:

- 15    - Base scan interval: the time interval at which the base cycle procedure scans through all the properly configured blocks, checking for changes in the on/off status, testing each according to its timing option and status to determine whether it should execute, and executing those that are due to execute.
- Next base cycle time: the time at which the supervisor procedure will actually do the next scan. This time should always be in the future, and should never be more than the base scan interval away.

20    - Current system status: provides information about what the supervisor procedure system is currently doing. Since the supervisor procedure only does its actions once every base scan interval, the system spends most of its time sleeping - *i.e.* waiting for the next cycle time to come. The normal system status values are:

- 25    \* Running-Sleeping : the normal status value. All control actions on the last scan have completed and the system is waiting for the next scan.
- \* Running-Computing : the system is currently performing block checks and executing blocks. Since calculations in the supervisor procedure finish rather quickly, this status will rarely be seen.
- \* Terminated normally: This status indicates that the supervisor procedure system has been stopped in an orderly way. Normally this status value will only be seen if the system manager has stopped the system, or briefly when a user performs the Update function on the user program menu.

30

[0285] An authorized user can change the base scan interval, stop the supervisor process (together with any auxiliary processes used for communication with PCS or other control systems), restart the supervisor process (and any auxiliary processes), or view the log file to which the base cycle procedure writes error reports and messages.

#### Block Initialization

[0286] Blocks are initialized when they are first turned on, or when the supervisor procedure is restarted after an outage of 30 minutes or more and the block had already been on. Block initialization sets the "last execution time" of the block to the current time. The "last execution time" value is used in fixed interval timing and also as a block monitoring parameter. If the block has a measured variable, the "last measured time" is set equal to the current time of the measured variable. This parameter is used when block timing is keyed off the measured variable. If the block timing is set to key off another block, the key block time is set equal to the last execution time of the key block. For feedforward blocks, the "old measured value" is set equal to the current value of the measured variable.

#### Build-Expert and Expert Procedures

[0287] The procedures for constructing an expert system from a domain expert's knowledge will now be described, together with the procedures by which the expert system is called up by the operating software (preferably the process control supervisor procedure, as described above).

[0288] It should be noted that the structures and advantages of the build-expert procedure are not entirely separate from those of the expert procedure (or procedures) generated thereby. The two procedures are preferably operated separately, but they are designed to for advantageous combination. The features of the expert procedure are partly designed to advantageously facilitate use of the build-expert procedure, and the features of the build-expert procedure and partly designed to advantageously facilitate use of the expert procedure.

[0289] The build-expert procedure works especially advantageously as an integral part of the supervisor procedure, which (in the presently preferred embodiment) is a VAX-based layered control system. The build-expert procedure produces complete FORTRAN subroutines that execute the expert actions. The supervisor procedure (*e.g.* via a user

program block) provides the functions for running an expert subroutine at specified times, and also provides callable routines that can be used by these subroutines to make and modify supervisor actions. The build-expert procedure can be used without the preferred supervisor procedure, but the user must provide a host program running at appropriate times to call the subroutines.

5

#### Preferred Menu Structure

[0290] In the presently preferred embodiment, the build-expert procedure is accessed by selecting the "User program" option on the top-level menu in the build-supervisor procedure (see Figure 16), entering the desired block number, and then selecting the Expert system development option on the user program menu. This will take the user to the build-expert procedure, which (in the presently preferred embodiment) presents a menu as shown in Figure 17.

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[0291] From this menu the user can access setup templates for the 3 rule types. The user also has access to functions for printing the rulebase, and for building a new expert subroutine.

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[0292] The rule templates used in the build-expert procedure allow the user to enter and modify the specification information for rules. The build-expert procedure is different from the build-supervisor procedure in the way it handles data. When a rule name is entered in the build-expert procedure and the RETURN or TAB key pressed, the letters are capitalized and the embedded spaces are transformed to underscores. This is how the build-expert procedure stores all character data. The other fields on rule templates are not transformed like this until the rule is stored. When the rule is recalled onto the template, the other fields will be capitalized with embedded blanks changed to underscores. In the presently preferred embodiment, the rule name, data type, and data number fields are the only fields on the rule tem-

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plates for which the user's entry is checked immediately (others may be modified in the future to do this). The remaining fields can be filled in with any data that the template allows (some fields accept only integers, some only alphabetics, etc). The data on the remaining fields is tested only when the user presses the keypad "-" to store the rule. The build-expert procedure then examines the data for errors, and requests corrections if needed. The build-expert procedure always checks rule names (and condition names) to be sure they are valid and meaningful where entered. In the presently preferred embodiment, the build-expert procedure checks other data for most errors, but it does not check for all conceivable errors. Data entered on a rule template is NOT stored until the keypad "-" key is pressed to store the rule. Data on a template will not be stored if the rule name field is blank. Data on a template can be lost if the user enters the data, then modifies the rule name field before pressing keypad "-". All the rule templates have a "delete rule" (keypad "-") and "top of form" (keypad 9) softkey. The delete rule key will ask the user to confirm the deletion by pressing the key again, and then deletes the rule from the rulebase. The top of form key simply takes the user to the top of the template.

25

[0293] After all the rules have been entered, the FORTRAN expert subroutine must be generated using keypad 9, "Generate Expert". Changes made in the rules will not become effective until the expert is rebuilt. When the build-expert procedure is used within the build-user-program environment (as discussed above), the FORTRAN subroutine is generated in the same directory with the user program and is named Blockn\_expert\_system.for, with the subroutine name Blockn\_expert\_system (n is the number of the block being worked on.) To use the expert from within the supervisor procedure, a one line user program must be written to call the expert. The one executable line is:

Call Blockn\_expert\_system .

40

#### Standardized Data Interface

[0294] The build-expert procedure uses a standard data interface. In the presently preferred embodiment, data sources are specified by a pair of integer parameters. One, the "data type", is a coded value which identifies the type of data desired and the data collection system from which the data is to come. The second, the "data number", identifies the specific data entity of that type within that system. Some data types (e.g. time averages) require a third parameter specifying the time over which to average.

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[0295] This system has several advantages. First, it provides a simple method of data identification in a many-system environment. Secondly, it allows the rules to easily reference data of many types from many diverse (and possibly remote) sources without requiring the user to write any custom program code for data retrieval. Some useful data sources might include: any lower level process control system; any supervisor process (whether running on the same hardware system or another); any process database (whether running on the same hardware system or another); or any computer which collects or generates data ("computer" being defined very broadly to include, e.g., any system which includes a microprocessor, such as a microprocessor based single loop controller).

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[0296] In the presently preferred embodiment, the data types allowed by the build expert procedure are: 1) the latest value of a database variable; 2) a time weighted average over a given time interval of the value of a database variable; 3) a simple average over a given time interval of the discrete data values of a database variable; 4) the feedback error of a feedback block in the supervisor process; 5) the change in the value of the measured variable of a supervisor

feedforward block since the last time the block acted; 6), 7) the goal values of control loops in two particular lower level control systems; 8) the second most recent value of a discretely sample process database variable; 9),10) the maximum and minimum limits for the manipulated variable value in a supervisor control block. Other sources could be used, for example any kind of parameter from any of the systems named in the previous paragraph, or system lexical functions (such as the system clock). As a further alternative, it might also be advantageous in some embodiments to make one of the options here a one-line blank, in which the user could enter a pointer to a callable procedure to fetch a variable value.

[0297] In the presently preferred embodiment, the user must specify the data type before the data number. When the data type is entered, a prompt line pops up on the template indicating the specific data type, which aids the user in entering the proper value for the data number. When the data number is entered, it is tested to be sure it is a meaningful entry for the data type specified. Some additional information is then displayed (such as a variable name and its units) to aid the user in confirming his input. These fields also serve to aid understanding of rule function and meaning when recalled for review or modification.

#### 15 Constructing the Expert System

[0298] An expert system goes through four steps in using knowledge: 1) The expert gets information from the outside world; 2) analyzes that information using its rules; 3) deduces the correct conclusion from its analysis; 4) communicates its decision to the outside world.

[0299] Rules state that WHILE one thing is true THEN something else must be true. For example, WHILE the composition of water in the Feed mix drum is greater than 12%, we say "FEED MIX WATER COMPOSITION" is "HIGH". Or, WHILE "FEED MIX WATER COMPOSITION" is "HIGH", AND "DEHY COLUMN BOTTOMS WATER" is "HIGH", we say "TOTAL SYSTEM WATER" is "TOO HIGH". WHILE "TOTAL SYSTEM WATER" is "TOO HIGH", we "Give a high water warning message."

[0300] This simple example shows the three basic types of rules which are used in the build-expert procedure: the sample retrieval rule described tests the VALUE (12%) of a process measurement (FEED MIX WATER), and assigns a value (HIGH, LOW, etc.) describing the condition of the measurement. The sample analysis rule given tests for combinations of values defined by other rules. If it finds the combination, the analysis rule creates a new condition (TOTAL SYSTEM WATER) and assigns a value (TOO HIGH) describing that condition. The sample action rule described tests for one specific condition (TOTAL SYSTEM WATER) has one specific value (TOO HIGH), and takes a specified action (Give a high water warning message)..

#### Sample Expert System

[0301] An example of construction of an expert system using novel methods and system as set forth in the present application will now be described in detail. The sample system here chooses an optimum control action from among three possibilities. A key element of the problem here is to control the composition of by-product MFB in the product stream of a refining train like that shown in Figure 7. MFB is separated in two columns in series. Essentially equivalent response in MFB composition can be achieved by changing the steam flow to either column. Both columns use high value steam in their reboilers. The first, the Xylene column, dumps the steam energy to cooling water. The second column, the MFB column, recovers most of the energy by generating steam overhead. Equipment limitations constrain both steam flows to within high and low limits.

[0302] As column feed rate varies, steam loading can change from minimum steam on both columns to maximum steam on both columns. The optimum operation maximizes steam on the low cost column (MFB) and minimizes steam on the high cost column (XYL).

[0303] In this example, control of the MFB composition is done statistically. The laboratory measurements of MFB are statistically tested using Shewhart tests. The Shewhart tests determine the on aim status of MFB: Off aim high, Off aim low, or on aim. When MFB is off aim, the Shewhart test generates an estimate of how far off aim MFB is. This estimate can be used to compute the feedback action needed to bring MFB back to aim: off aim high requires an increase in steam to the two columns, off aim low requires a decrease.

[0304] The expert system which is sought to be developed should instruct the supervisor procedure to make the least cost control action. Plant startup, problems, or poor manual operation may distribute steam in a non-optimal way, and this cannot be known beforehand. The objective will be to move toward the optimum steam distribution through control action response to off aim conditions. Steam will not be shifted for cost savings only, since this complicates control and may negatively affect quality.

[0305] Although this may seem like a trivial decision, it actually involves considering 3 variables in the correct sequence. This is where the "expertise" gets into the "expert" system. Developing the logic is the task of the human expert, and the system disclosed herein merely expedites the transfer of that logic into the expert system. The process

control decision tree which will be implemented, in the sample embodiment described, is as follows: First, decide whether to add or cut steam:

5 (1) If adding steam:

[0306]

- (1.1) First check the MFB column. If MFB column steam below maximum, add steam here.
- 10 (1.2) If the MFB column steam is maximum, then (1.2.1) Check the Xylene column. If xylene column steam is below the maximum, add steam here.
- (1.2.2) If xylene column steam is maximum, the user cannot add steam. To get MFB on aim, feed to the column must reduced. Cut column feed.

15 (2) If cutting steam:

[0307]

- 20 (2.1) First, check the xylene column. If xylene column steam is above the minimum, cut steam here.
- (2.2) If xylene column steam is minimum, then
  - (2.2.1) Check the MFB column. If MFB columns steam is above minimum, cut steam here.
  - (2.2.2) If MFB column steam is minimum, the user cannot cut steam. To get MFB on aim, Feed to the column must be increased. Add column feed.

25 [0308] It is highly desirable that the decision tree being implemented should cover all the possible cases, and that the conclusions should be mutually exclusive. If it does not cover all the possible cases, the expert will sometimes be unable to come to a conclusion. If the conclusions are not mutually exclusive, then more than one conclusion could exist. Although this might logically be possible, this condition might mean unpredictability as to which conclusion will be reached, so that there would not be a reproducible basis for action.

30 [0309] Domain experts, in performing the analytical steps which the expert system should ideally emulate, will carry out many steps implicitly; but implementing a process in a computer requires that each step be expressly spelled out. To make the decision, the user must first specify:

- 35 - what measurements will be used to evaluate the process condition (in this example, MFB\_STEAM, XYL\_STEAM, DIRECTION\_OF\_CHANGE);
- what ranges of values of the measurements (e.g. 40 > XYL\_STEAM) match what status values for the measurements (e.g. MID\_RANGE);
- what combinations of status values (e.g. MFB\_STEAM is MAX and XYL\_STEAM is MIN, and DIRECTION\_OF\_CHANGE is ADD) will result in what other conditions (e.g. ACTION is CHANGE\_XYL\_STEAM);
- what must be done to make the desired action happen.

[0310] The detailed specifications needed to handle this problem are defined as follows:

45 [0311] Measurements: For MFB column steam, the goal on the computer loop for MFB steam is a good measure. In the sample system referred to, this is loop 30 in the "DMT PCS" system. For xylene column steam, the goal on the computer loop is a good measure. In the sample system referred to, this is loop 5 in the "DMT PCS" system. For the direction or change, the best measure is the feedback error on the control block that will be changing steam (in this case, the third block in the supervisor procedure). For MFB column steam, we know the operating limits of steam flow to the column (in thousands of pounds per hour (MPPH)):

50 MAX > 49.5;  
MIN < 28.5;  
MID > 28.5 < 49.5.

55 And for the xylene column:

MAX > 66.5  
MIN < 40.5

MID > 40.5 < 66.5.

For the direction of action, we know that an off aim high condition means a steam increase. Our feedback block (in the supervisor procedure) is using the Shewhart deviation from aim as the measured variable, with an aim of 0.0. Thus if the feedback error is positive, we increase steam:

AND if Feedback error > 0  
CUT if Feedback error < 0 or = 0

[0312] For the analysis of these conditions, we need to specify what combinations of conditions lead to what result. This expert provides only one result: it defines what the manipulated variable will be - xylene column steam ("xyl\_col\_steam"), MFB column steam ("MFB\_col\_steam"), or column feed ("column\_feed"). This logic results in the following rules:

15

Table 5

MANIPULATED_VARIABLE is MFB_COLUMN_STEAM While		
Direction_of_change and MFB_COL_STEAM	is is	ADD not MAX
MANIPULATED_VARIABLE is XYL_COLUMN_STEAM While		
Direction_of_change and MFB_COL_STEAM and XYL_COL_STEAM	is is is	ADD MAX not MAX
MANIPULATED_VARIABLE is COLUMN_FEED While		
Direction_of_change and MFB_COL_STEAM and XYL_COL_STEAM	is is is	ADD MAX MAX
MANIPULATED_VARIABLE is XYL_COLUMN_STEAM While		
Direction_of_change and XYL_COL_STEAM	is is	CUT not MIN
MANIPULATED_VARIABLE is MFB_COLUMN_STEAM while		
Direction_of_change and XYL_COL_STEAM and MFB_COL_STEAM	is is is	CUT MIN not MIN
MANIPULATED_VARIABLE is COLUMN_FEED While		
Direction_of_change and XYL_COL_STEAM and MFB_COL_STEAM	is is is	CUT MIN MIN

[0313] Note that: 1) some of the conditions are negated, i.e. it is specified that a rule or condition must NOT have a certain value (MFB\_COL\_STEAM is NOT MIN). 2) More than one test can set the value of the same condition (MANIPULATED\_VARIABLE in this case). 3) More than one test can assign the same value to the same condition (i.e. the second and fourth both set MANIPULATED VARIABLE to XYL\_COL\_STEAM, under different conditions). By contrast, the retrieval rules each assign one of several descriptors to a name which is unique to that specific rule.

[0314] Finally, the expert must do something with its conclusion to change the way the supervisor acts. In this case, assume that there are three feedback blocks in the supervisor procedure, all having the Shewhart MFB deviation as measured variable, with aims of 0.0. One (#3) manipulates xyl\_COL\_steam, one (#4) MFB\_column steam, and one (#5) column feed rate. The supervisor procedure includes a FORTRAN callable function named ACS\_SELECT\_BLOCK, which allows only one block out of a set to take action. The others are "de-selected" and stand ready to act if selected. When ACS\_select\_block is called, the first block number in the argument list becomes selected, the others are deselected. Trailing zeros are ignored.

[0315] Thus, to enable the expert being built to change the control strategy, the following rules are added to the rule

set:  
 While MANIPULATED VARIABLE is XYL\_COL\_STEAM Then  
   do the FORTRAN statement:  
     ACS\_status = ACS\_select\_block ( 3, 4, 5, 0, 0, 0 )  
 5 While MANIPULATED VARIABLE is MPB\_COL\_STEAM Then  
   do the FORTRAN statement:  
     ACS\_status = ACS\_select\_block ( 4, 3, 5, 0, 0, 0 )  
 While MANIPULATED VARIABLE is COLUMN FEED Then  
   do the FORTRAN statement:  
 10   ACS\_status = ACS\_select\_block ( 5, 3, 4, 0, 0, 0 )

The foregoing data entries are all the inputs needed to define the expert system.

[0316] Within the supervisor procedure, an expert system can be developed for each block. Used in this way, the build-expert procedure will create the FORTRAN subroutine Blockn\_expert\_system (where n is the block number, i.e. the subroutines will be named BLOCK2\_EXPERT\_SYSTEM etc.), compile it, and place it in the proper library so that 15 it can be called from within a supervisor block (by a user routine).

#### Expert Rule Structure

[0317] This sample embodiment provides an example which may help clarify what an expert procedure does. Some 20 more general teachings regarding expert system methods and structure will now be set forth.

[0318] Figure 2 is a schematic representation of the organization preferably used for the knowledge base. Three 25 main categories of rules are used, namely retrieval rules 210, analysis rules 220, and action rules 230.

#### Retrieval Rules

[0319] The retrieval rules 210 each will retrieve one or more quantitative inputs (which may be, e.g., sensor data 30 157 from one of the sensors 156, historical data 141 and/or laboratory measurements 162 from a historical data base 140, limits on variable values, goals 132 defined by the supervisor procedure 130, combinations of these, or other inputs). One of the significant advantages of the system described is that it provides a very convenient user interface 35 for accessing quantitative inputs from a very wide range of sources: essentially any data object which can be reached by the host computer can be used. (The presently preferred embodiment uses DECnet and serial communication lines to link the computer which will be running the expert system with the various computers it may be calling on for data, but of course a wide variety of other networking, multiprocessor, and/or multitasking schemes could be used instead.)

[0320] In the presently preferred embodiment the retrieval rules are of two kinds: the simpler kind (referred to as 40 "variable rules") will name one quantitative value (which may optionally be derived from several independently accessed quantitative inputs), and assign one of a predetermined set of descriptors (variable status values 222) to that name. Each of the more complex retrieval rules (referred to as "calculation rules") permits descriptors to be assigned selectively to a name in accordance with one or more calculated values (which may optionally be derived from a number of quantitative variables).

[0321] Figure 3 shows the template used for a retrieval rule in the presently preferred embodiment, together with a 45 sample of a retrieval rule which has been entered into the template. The areas in this drawing which are surrounded by dotted lines indicate the parts of the template which the user can modify, and which are preferably highlighted to the user in some fashion, e.g. by showing them in reverse video. In this example, the user has typed in the rule name as "xylene column steam." The build-expert software has automatically translated this rule name, by changing all the spaces in it to underscores, so that it appears as a one word name. (This can be conveniently used as part of a variable name in conventional computer languages.) Thus, the rule shown in Figure 3, when translated into an expert procedure 50 by the build-expert procedure, will define a set of variables whose names each begin with "XYLENE\_COLUMN\_STEAM."

[0322] For example, in the presently preferred embodiment the rule shown will translate into the following set of 55 variables:

[0323] "XYLENE\_COLUMN\_STEAM\_STATUS" is a character variable (also known as a string or alphanumeric variable) which will have a string value which is either "MIN," "MAX," or "MID;"

[0324] "XYLENE\_COLUMN\_STEAM\_VALUE" will be a real variable, representing the quantitative value originally 60 retrieved for the parameter;

[0325] "XYLENE\_COLUMN\_STEAM\_AGE" will be an integer variable representing the age of the quantitative value originally retrieved;

[0326] "XYLENE\_COLUMN\_STEAM\_ASTAT" will be a character variable which is defined to have values of "TOO\_OLD" or "OK," depending on whether the age value is within limits (note, for example, that this variable could 65

easily be configured as a logical variable instead);

[0327] and "XYLENE\_COLUMN\_STEAM\_FIRED" will be a logical variable which indicates whether this particular rule has been fired (on a given pass).

[0328] In filling out the retrieval rule template, the user must fill in at least two of the classification blanks. However, in the presently preferred embodiment, only five classification ranges are permitted. (This limit could be changed, but there are significant advantages to permitting the user to input only a restricted number of ranges. Where the process control algorithm absolutely demands that the variable be classified into more ranges, two or more process variable rules could be used to label up to eight or more ranges.)

[0329] Another constraint used in the presently preferred embodiment is that the user must enter at least the first two open ended ranges. He may enter up to three bounded ranges, to provide a complete coverage of all cases, but he must enter at least two open ended range specifications.

[0330] In the presently preferred embodiment, the build-expert procedure checks to see that the ranges defined are comprehensive and non-overlapping, before the rule is permitted to be added to the rule base.

[0331] Figure 4 shows an example of a different kind of retrieval rule, known as a calculation rule. The menu for this rule is (in the presently preferred embodiment) presented to the user as two screens. The user may specify up to ten quantitative inputs, of any of the types just referred to, as well as up to ten values arithmetically derived from these inputs (or constants). By having some of the derived values refer back to other ones that are derived values, quite complex formulas may be implemented. (One advantageous use of such formulas may be to relate off-line time-stamped laboratory measurements with the continuously-measured values of the same (past) time era, e.g. in a component material balance.) Moreover, notice that the variable values and calculated values thus assembled may be used not only to define a "key value" to be categorized, but also to define the limits of the various categories against which the key value is sought to be tested.

#### Analysis Rules

[0332] Analysis rules generally are used to embed the natural language reasoning as practiced by the domain expert. One important distinction between retrieval rules and analysis rules is that each retrieval rule has a unique name, but the analysis condition names defined by analysis rules are not necessarily unique. Figure 5 shows an example of an analysis rule 220. Again, the portions of the template which the user can modify are shown inside dashed boxes. Note that the template preferably used defines an analysis condition name and assigns a descriptor to that analysis condition name if specific conditions are met. In the presently preferred embodiment, the only tests permitted are ANDed combinations of no more than five logical terms, each of which can consist only of a test for identity (or non-identity) of two strings. Moreover, the string identity tests are preferably set up so that each of the comparisons either tests a retrieval rule name to see if a certain variable status value 212 was assigned by that rule, or tests an analysis condition name to see if a certain analysis status value 222 was assigned by one of the analysis rules. That is, as seen schematically in Figure 2, there is potential for recursion among the analysis rules 220 considered as a group, since some of the analysis rules 220 can refer to the outputs of other analysis rules 220. Optionally the analysis rules could be sequenced so that there would never be any open-ended recursions, but in the presently preferred embodiment this extra constraint is not imposed.

[0333] Any one analysis condition name may (under various conditions) be assigned values by more than one analysis rule. That is, each analysis rule is preferably set up as an IF statement, and multiple such IF statements will typically be needed to specify the various possible values for any one analysis condition name.

[0334] In the presently preferred embodiment, the status of every analysis condition name and variable rule name are initially defined to be "unknown," and the logical comparisons are implemented so that no test will give a "true" result if one term of the comparison has a value of "unknown."

[0335] The order in which the analysis rules are executed may be of importance where an analysis condition name is multiply defined. That is, it may in some configurations be useful to permit the conditions of the various analysis rules 220 to be overlapping, so that, under some circumstances, more than one analysis rule may find a true precondition and attempt to assign a status value to the same analysis condition name. In this case, the sequence of execution of the analysis rules 220 can optionally be allowed to determine priority as between analysis rules. However, as mentioned above, this is not done in the presently preferred embodiment.

[0336] Moreover, more than one analysis rule may assign the same analysis status value 222 to the same analysis condition name, under different circumstances.

[0337] It can be advantageous, for purposes of documenting the reasoning embedded in the expert system, to give names to the analysis rules which include both the name and descriptor possibly linked by that rule: thus, for instance, a rule which is able to conclude that column operation is normal might be named "COLUMN\_OP\_NORMAL."

Action Rules

5 [0338] Figure 6 shows the presently preferred embodiment of the template for action rules, and an example of one action rule which has been stated in this format. Again, the portions of the template which the user can modify are indicated by dashed boxes.

10 [0339] The user has chosen to name this particular action rule "Change Xylene Steam," which the build-expert software has translated into CHANGE\_XYLENE\_STEAM (for incorporation into various variable names such as "CHANGE\_XYLENE\_STEAM\_-FIRED"). The names assigned to action rules are primarily important for documentation, so that, when this user or another user looks back through the rule base, the use of clear rule names for action rules will help to understand what the structure of the expert system's inference chaining is. In fact, it may be advantageous, as in the example shown, to generally pick analysis status values 222 which have fairly descriptive names, and then, to the extent possible, name the action rules identically with the corresponding analysis status values.

15 [0340] Note also that the action rules can refer back to a variable status value 212 as well as to an analysis status value 222.

20 [0341] Thus, in the presently preferred embodiment the action rules embody an absolute minimum of logic. They are used primarily as a translation from descriptive key words embedded within the inference chaining structure to the actual executable statements (or command procedures) which specify the action to be taken. Thus, one way to think about the advantages of the expert system organization preferably used is that the emulation of natural language reasoning is concentrated as much as possible in the analysis rules, while the retrieval rules are used to provide translation from quantitative measurements into input usable with natural language inference rules, and the action rules are used almost exclusively to provide translation from the natural language inference process back to executable command procedures which fit in well with the computer system used.

25 [0342] Each of the action rule templates also gives the user several choices for the action to be taken to implement the action rule if its precondition is met. The user can either insert an executable statement (in FORTRAN, in the presently preferred embodiment) or insert a pointer to a command procedure, or simply have the action rule send advisory messages. The third option is useful for debugging, since the expert can be observed to see what actions it would have taken, without risking costly errors in the actual control of the system.

30 [0343] In the example shown, an executable FORTRAN statement is used, but the statement specified merely passes an action code back to the supervisor process. In the example shown in Figure 6, the procedure call given will cause the supervisor procedure to turn on the block whose number is given first, and turn off all other blocks whose numbers are given. Thus, the statement

acs-status = acs\_select\_block (3, 4, 5, 0, 0, 0)

35 would change the status of block 3 to "on-selected" (assuming that it did not need to be initialized), and would set the status values of blocks 4 and 5 to "on-deselected." Thus, when the expert system has completed running, the supervisor procedure which called the expert procedure as a subroutine can selectively execute block functions depending on the values passed back to it by the subroutine.

40 [0344] Thus, the action rules permit a very large variety of actions to be performed. For example, one optional alternative embodiment provides synthetic-speech output; optionally this can be combined with a telephone connection, to permit dial-out alert messages (e.g. to a telephone number which may be selected depending on the time of day shown by the system clock, so that appropriate people can be notified at home if appropriate).

45 [0345] Another optional embodiment permits an action rule to call up a further sub-expert. This might be useful, for example, if one expert subprocedure had been customized to handle emergency situations-who should be called, what should be shut down, what alarms should be sounded.

Generating the Expert Procedure

50 [0346] After the user has input as many rule statements as needed, or has modified as many of an existing set of rule templates as he wishes to, he can then call the generate code option to translate the set of templates 115, including the user inputs which have been made into the rule templates, to create the expert system 120.

Generating Source Code

55 [0347] As a result of the constraints imposed in the various rule templates, the translation from the constrained format of the templates is so direct that the executable rules can be generated simply by a series of appropriate string-equivalent tests, string-append operations, logical-equivalence tests, arithmetic operations, and fetches.

[0348] Preferably three passes are performed: the first does appropriate character type declarations; the second loads the appropriate initializations for each rule; and the third translates the inference rules themselves.

[0349] An example of the initialization steps is seen in initialization of the analysis rules: an initial value such as

"dont\_know" is assigned to each condition name, and the equivalence tests are redefined slightly by the translation procedure, so that, until some other value is assigned to the name by another rule, the statement  
 "name" = "descriptor"  
 will be evaluated as false, and the statement  
 5 NOT("name" = "descriptor")  
 will also be evaluated as false.

Sample Source Code

10 [0350] A portion of the source code for the procedure which actually performs this function, in the presently preferred embodiment, is as follows.

Table 6

```

15
20
25
30
35
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55

*****  

C  

C      Build_expert.for  

C  

C      Routine to generate FORTRAN expert system code using  

C      the process rulebase.  

C  

C  

*****  

C  

C      Subroutine Build_expert  

C  

C      Include 'pace$includes:Variable_params.inc'  

C      Include 'pace$includes:Expert_data.inc'  

C      Include 'pace$includes:Analysis_commons.inc'  

C      Include 'pace$includes:Analysis_rules.inc'  

C      Include 'pace$includes:Action_commons.inc'  

C      Include 'pace$includes:Action_rules.inc'  

C      Include 'pace$includes:Action_params.inc'  

C  

C      Logical First  

C      Logical No_more  

Character*25    Last_cond  

Character*80    code_dir_file

```

```

5          Character*80    Directory
          Integer*2     L_dir
          Character*39   Subroutine_name
          Character*14   Subprocess_name
          Character*3     Cblock
          Integer*2     L_sp
          Character*1     Search_string
          Integer*2     Srlen

10         C
          Call Fdv$Putl(' Generating Expert System code....')
          C
15         C...Rewind the code file
          C
          d   write(6,*):' will rewind code file'
          Rewind ( Unit = Code_lun )
          Next_label = 2

20         C
          C...Get the name of the expert system code file, pick out the C subroutine name
          from it
          C
          d   Call Fdv$Putl ('Will translate logicals.')
25         Call Lib$sys_trnlog ( 'PACE$RULES' ,, Directory   ,,,)
         Call Lib$sys_trnlog ( 'PACE$CODE'  ,, Code_dir_file ,,,)
          d   Call Fdv$Putl ('Did translate logicals.')
          Istart = Index ( Code_dir_file, 'J' )
          Subroutine_name = Code_dir_file(Istart+1:80)//Blank
30         d   Call Fdv$Putl ('Will get index of ."')
          Iend   = Index ( Subroutine_name, '.' )
          d   Call Fdv$Putl ('Will clip subroutine name.')
          If ( Iend .gt. 1 ) Then
              Subroutine_name = Subroutine_name(1:Iend-1)//Blank
35         Else
              Subroutine_name = 'Expert'//Blank
          End If
          d   Call Fdv$Putl ('Will trim subroutine name.')
          Call Str$Trim ( Subroutine_name, Subroutine_name, Srlen )
          d   Write ( 6, 100 ) Subroutine_name
          Write ( Code_lun, 100 ) Subroutine_name

          C
40         C...construct a sub-process name
          C
          If ( Subroutine_name(1:5) .eq. 'BLOCK' ) Then
          d   Call Fdv$Putl('Is block.')
          d   Call Fdv$Wait ( It )
          50     Read ( Subroutine_name(6:8), '(13)' ,err= 91 ) Iblock
          d   Call Fdv$Putl('Is' > 99.)
          d   Call Fdv$Wait ( It )
          Liblock = 3
          Go To 93
          55     91   Read ( Subroutine_name(6:7), '(12)' ,err= 92 ) Iblock

```

```

d      Call Fdv$putl('Is > 9.')
d      Call Fdv$wait ( It )
5      lblock = 2
      Go To 93
92      Read ( Subroutine_name(6:6), '(I1)' ,err= 93 ) lblock
d      Call Fdv$putl('Is < 10.')
d      Call Fdv$wait ( It )
10      lblock = 1
      Go To 93
93      Write ( Cblock, '(I3)' ) lblock
      lstart = 4 - lblock
      Subprocess_name = 'B'//Cblock(lstart:3)//'_'
15      L_sp = 3 + lblock
      Else
      L_sp = 1
      End If
20      C
100     Format(
1 '      Options /Extend_source', /,
1 '*****', /,
1 'C', /,
25     1 'C'   Expert System Code', /,
1 'C', /,
1 '*****', /,
1 'C', /,
30     1 '      Subroutine ', A, /,
1 'C', /,
1 '      Include ''ACSS$includes:ACSServ.inc''', /,
1 '      Include ''ACSS$includes:ACSStatus.inc''', /,
1 '      Include ''ACSS$includes:Sys_functions.inc''', /,
35     1 '      Include ''($Jpidef)'', /,
1 '      Integer*4      Vss$_to_ascii_time', /,
1 '      Integer This_pass_fires', /,
1 '      Character*25    Unknown', /,
1 '      Parameter      ( Unknown = ''Unknown'' )', /,
40     1 '      Character*25  OK', /,
1 '      Parameter      ( OK = ''OK'' )', /,
1 '      Character*25  Too_old', /,
1 '      Parameter      ( Too_old = ''Too_old'' )', /,
45     1 '      Integer*4      Now', /,
1 '      Integer*4      Then', /,
1 '      Character*18    C_now', /,
1 '      Integer*4      Itemlist(4)', /,
1 '      Integer*2      Code(2)', /,
50     1 '      Equivalence   ( Itemlist(1) , Code(1) )', /,
1 '      Integer*4      Node', /,
1 '      Integer*2      Len', /,
1 '      Character*80    Line', /,
55     1 'C'
1 )

```

```

d      write(6,*) ' wrote header info.'
C
5
C..Make declaration code for variable rules
C
C
C      First = .true.
1   Continue
C
70
C..Read A rule
C
C      Call Read_var_rule_params ( First , No_more )
C      If ( No_more ) Go To 200
C
15
C..Write out FORTRAN declarations
C
C      Call Str$Trim ( Rule_name , Rule_name , Len )
C      Write ( Code_lun , 101 ) (Rule_name(1:Len) , J=1,5 )
C
20
101   Format (
C      1 '      Real*4      ', A , '_value'      , / ,
C      1 '      Integer*4     ', A , '_age'      , / ,
C      1 '      Character*25   ', A , '_stat'     , / ,
C      1 '      Logical*1     ', A , '_fired'    , / ,
C      1 '      Character*10   ', A , '_estat'    , / ,
C      1 'C'
C      1 )
C
C
30
C      Go To 1
C
C
200   Continue
C
C..Make declaration code for calculation rules
C
C      Call Declare_calc_rules
C
C..Make declaration code for analysis rules
C
40
C
C
C      Last_cond = ''
C      First = .True.
C
45
2   Continue
C
C..Read A rule
C
C
50
C      Call Read_anal_rule_params ( First , No_more )
C      If ( No_more ) Go To 201
C
C..Write out FORTRAN declarations
C
C
55
C      Call Str$Trim ( An_cond_name , An_cond_name , Len )
C      Call Str$Trim ( An_rule_name , An_rule_name , lLen )

```

```

5      Write ( Code_lun , 104 )
      If ( An_cond_name .ne. Last_cond )
1       Write ( Code_lun , 102 ) (An_cond_name(1:len) )
      Write ( Code_lun , 103 ) (An_rule_name(1:llen) )
      Last_cond = An_cond_name
10     Format (
1       Character*25      ' , A , '_stat'
1 )
103    Format (
1       Logical*1      ' , A , '_fired'
1 )
15     104 Format (
1       'C'
1       )
C
20     Go To 2
C
201   Continue
C
C..Make declaration code for action rules
25
C
C
30     First = .True.
252   Continue
C
C..Read A rule
35
C
C
40     Call Read_action_rule_params ( First , No_more )
      If ( No_more ) Go To 251
C
C..Write out FORTRAN declarations
45
C
C
50     Call StrStrim ( Ac_rule_name , Ac_rule_name , Len )
      Write ( Code_lun , 262 ) Ac_rule_name(1:len)
262    Format (
1       Logical*1      ' , A , '_fired'      , /
1       'C'
1 )
C
45     Go To 252
C
251   Continue
C
C
55     C...Now Write Initialization code
C
      Write ( Code_lun , 401 ) Subroutine_name (1:Srlen)
401   Format (
1       'C' , /
1       'C'      Initialize the status values. ' , /

```

```

5      1 'C' , / ,
      1 '      Van_status = Vass_from_ascii_time ( '' '' , Now )' , / ,
      1 '      Van_status = Vass_to_ascii_time ( Now , C_Now )' , / ,
      1 '      Code(1) = 4' , / ,
      1 '      Code(2) = Jpi$_mode' , / ,
      10     Itemlist(2) = Xloc(Mode)' , / ,
      1 '      Itemlist(3) = Xloc(len)' , / ,
      1 '      Itemlist(4) = 0' , / ,
      1 '      sys_status = sys$getjpiw (,,,Itemlist,,,)' , / ,
      1 'd      Write(6,901) C_now' , / ,
      1 '901 Format ( / , " Running " , A , " at " , A )' , / ,
      1 'C'
      1 )

C
C....Initialize variable rules - This will set logical flags false and
C      retrieve the necessary data for the rule.
20
C
      First = .True.
      402 Continue

C
C
25      C..Read A rule
C
      Call Read_var_rule_params ( First , No_more )
      If ( No_more ) Go To 420

30
C
      Call StrStrim ( Rule_name , Rule_name , Len )
      Write ( Code_lun , 403 ) ( Rule_name(1:Len) , J=1,4 )
      403 Format (
      1 'C' , / ,
      1 'C....' , A , ' rule initialization' , / ,
      1 'C' , / ,
      1 '      ' , A , '_stat = Unknown' , / ,
      1 '      ' , A , '_stat = Unknown' , / ,
      1 '      ' , A , '_fired = .False.' )
40
C
      If ( Ret_meth .eq. Current_val ) Then
        Write ( code_lun , 404 ) Var_num , (Rule_name(1:Len),J=1,2)
      404 Format (
      1 '      Call Get_cur_data ( ' , 14 , ' , ' , A , '_value , ' , A , '_age
      )'
      1 )

      Else If ( Ret_meth .eq. Discrete_avg ) Then
        Write ( code_lun , 405 ) Ret_time , Var_num , (Rule_name(1:Len),J=1,2)
45
      405 Format (
      1 'C' , / ,
      1 '      Then = Now + ' , 112 , / ,
      1 '      Call Get_disc_avg_data ( ' , 14 , ' , ' , A , '_value , ' , A ,
55

```

```

5      '_age , Then , Now )'
6      1 )
7      Else If ( Ret_meth .eq. Time_ut_avg ) Then
8          Write ( code_lun , 406 ) Ret_time , Var_num , (Rule_name(1:len),j=1,2)

10     606      Format (
11         1 'C' , / ,
12         1 '      Then = Now + ' , I12 , / ,
13         1 '      Call Get_time_ut_avg_data ( ' , I4 , ' , ' , A , '_value , ' , A
14         , '_age , Then , Now )'
15         1 )
16     Else If ( Ret_meth .eq. Sec_last_vant_point ) Then
17         Write ( code_lun , 411 ) Var_num ,
18         1 Rule_name(1:len)
19     411      Format (
20         1 'C' , / ,
21         1 '      Call Get_sec_last_vant_point ( ' , I4 , ' , ' , A , '_value ,
22         Itime_stamp )'
23         1 )
24     Else If ( Ret_meth .eq. ACS_ff_delta ) Then
25         Write ( code_lun , 407 ) Var_num , Rule_name(1:len)
26     407      Format (
27         1 'C' , / ,
28         1 '      ACS_status = ACS_get_FF_delta ( ' , I4 , ' , ' , A , '_value )'
29         1 )
30     Else If ( Ret_meth .eq. ACS_fb_error ) Then
31         Write ( code_lun , 408 ) Var_num , Rule_name(1:len)
32     408      Format (
33         1 'C' , / ,
34         1 '      ACS_status = ACS_get_fb_error ( ' , I4 , ' , ' , A , '_value )'
35         1 )
36     Else If ( Ret_meth .eq. PCS_DMT_loop_goal ) Then
37         Write ( code_lun , 409 ) Var_num , Rule_name(1:len)
38     409      Format (
39         1 'C' , / ,
40         1 '      ACS_status = ACS_get_PCS_goal ( ''DMT      ' , ' ,
41         1 I , ' , ' , A , '_value )'
42         1 )
43     Else If ( Ret_meth .eq. PCS_TPA_loop_goal ) Then
44         Write ( code_lun , 410 ) Var_num , Rule_name(1:len)
45     410      Format (
46         1 'C' , / ,
47         1 '      ACS_status = ACS_get_PCS_goal ( ''TPA      ' , ' ,
48         1 I , ' , ' , A , '_value )'
49         1 )
50     Else
51         Write( Code_lun , * ) 'C....Bad retrieval method'
52     End If
53
54     C
55     Write ( Code_lun , 510 ) (Rule_name(1:len),j=1,2)

```

```

5      S10  Format (
6          1 'd    Write(6,*), A, '_value = '' , 1 , A, '_value' )
7      C
8          Go To 402
9      C
10         420  Continue
11      C
12         C...Initialize calculation rules
13      C
14             Call Init_calc_rules
15      C
16         C...Initialize analysis rules
17      C
18             Last_cond = ''
19             First = .True.
20         440  Continue
21      C
22      C
23         C..Read A rule
24      C
25             Call Read_anal_rule_params ( First , No_more )
26             If ( No_more ) Go To 450
27      C
28             Call StrStrim ( An_cond_name , An_cond_name , Len )
29             Call StrStrim ( An_rule_name , An_rule_name , ILen )
30             Write ( Code_lun , 441 ) ( An_rule_name(1:ILen) , J =1,2 )
31             If ( An_cond_name .eq. Last_cond ) Go To 440
32             Last_cond = An_cond_name
33             Write ( Code_lun , 442 ) ( An_cond_name(1:Len) , J =1,1 )
34         441  Format (
35             1 'C' , /
36             1 'C....' , A , ' rule initialization' , /
37             1 'C' , /
38             1 'C' , A , '_fired = .False.' )
39         442  Format (
40             1 'C' , A , '_stat = Unknown' )
41      C
42          Go To 440
43      C
44         450  Continue
45      C
46         C...Initialize action rules
47      C
48             First = .True.
49         460  Continue
50      C
51      C
52         C..Read A rule
53      C
54             Call Read_action_rule_params ( First , No_more )

```

```

    If ( No_more ) Go To 490
    C
    Call Str$Trim ( Ac_rule_name , Ac_rule_name , Len )
    Write ( Code_lun , 461 ) ( Ac_rule_name(1:Len) , J =1,2 )
    461 Format (
    1 'C' , / ,
    1 'C....' , A , ' rule initialization' , / ,
    1 'C' , / ,
    1 '    ' , A , '_fired = .False.' )
    C
    Go To 460
    490 Continue
    C
    500 Continue
    C
    C...Write the rule code
    C
    Write ( Code_lun , 501 )
    501 Format (
    1 'C' , / ,
    1 '    1 Continue' , / ,
    1 'C' , / ,
    1 '    This_pass_fires = 0' , / ,
    1 'C'
    1 )
    C
    C
    C...Write out variable rule code
    C
    First = .True.
    C
    502 Continue
    C
    C..Read A rule
    C
    Call Read_var_rule_params ( First , No_more )
    If ( No_more ) Go To 600
    C
    Call Str$Trim ( Rule_name , Rule_name , Len )
    C
    If ( Age_limit .eq. Empty ) Age_limit = -365*24*60*60
    C
    Write ( Code_lun , 299 ) ( Rule_name(1:Len),J=1,3) , Abs(Age_limit) ,
    1 ( Rule_name(1:Len),J=1,2)
    299 Format (
    1 'C' , / ,
    1 'C....' , A , ' Rules ' , / ,
    1 'C' , / ,
    1 '    If ( ' , /
    1 '        1 ( ' , A , '_estat .eq. Unknown ) .end. ' , / ,
    55

```

```

1 :   1   (' , A , '_age .le. ' , I , ' ) ' , / ,
1 :   1   ) Then ' , / ,
5   1   ' , A , '_astat = OK ' , / ,
1 :d   Write(6,*)' , A , '_age is OK.' , / ,
1 :   This_pass_fires = This_pass_fires + 1' , / ,
1 : End If'
1 )

10   C
      Write( Code_lun , fmt=298 ) ( Rule_name(1:len),J=1,2) , Abs(Age_limit) ,
      1   ( Rule_name(1:len),J=1,2)

15   298 Format (
      1 'C' , / ,
      1   If ( ' , / ,
      1   1   (' , A , '_astat .eq. Unknown ) .and. ' , / ,
      1   1   (' , A , '_age .gt. ' , I , ' ) ' , / ,
      20  1   ) Then ' , / ,
      1   ' , A , '_astat = Too_old' , / ,
      1 :d   Write(6,*)' , A , '_age is Too_old.' , / ,
      1   This_pass_fires = This_pass_fires + 1' , / ,
      1 : End If'
      1 )

25   C
      Write( code_lun , 505 ) (Rule_name(1:len),J=1,3) , Log_opt , Limit1 ,
      1   Rule_name(1:len) , Status1 , Rule_name(1:len) ,
      1   Status1 , Rule_name(1:len)

30   505 Format (
      1 'C' , / ,
      1   If ( ' , / ,
      1   1   (' .not. ' , A , '_fired ) .and. ' , / ,
      1   1   (' , A , '_astat .eq. OK ) .and. ' , / ,
      35  1   1   (' , A , '_value ' , A4 , ' ' , F12.5 , ' ) ' , / ,
      1   1   ) Then ' , / ,
      1   ' , A , '_stat = '' , A25 , ' ' , / ,
      1 :d   Write(6,*)' , A , '_stat is ' , A , ' ' , / ,
      40  1   ' , A , '_fired = .True.' , / ,
      1   This_pass_fires = This_pass_fires + 1' , / ,
      1 : End If'
      1 )

45   C
      Write( code_lun , 506 ) (Rule_name(1:len),J=1,3) , Log_op8 , Limit8 ,
      1   Rule_name(1:len) , Status8 , Rule_name(1:len) ,
      1   Status8 , Rule_name(1:len)

50   506 Format (
      1 'C' , / ,
      1   If ( ' , / ,
      1   1   (' .not. ' , A , '_fired ) .and. ' , / ,
      1   1   (' , A , '_astat .eq. OK ) .and. ' , / ,
      1   1   (' , A , '_value ' , A4 , ' ' , F12.5 , ' ) ' , / ,
      55  1   1   ) Then ' , / ,

```

```

1 '      ' , A , '_stat = ''', A25 ,'''', / ,
1 'd      Write(6,*)' , A , '_stat is ' , A ,'''', / ,
1 '      ' , A , '_fired = .True.' , / ,
1 '      This_pass_fires = This_pass_fires + 1' , / ,
1 'End If'
1 )

C
10      If ( Status2 .ne. ' ' ) Then
C
15      Write( code_lun , 508 ) (Rule_name(1:len),j=1,3) , Log_op2 , Limit2 ,
1      Rule_name(1:len) , Log_op3 , Limit3 ,
1      Rule_name(1:len) , Status2 , Rule_name(1:len) ,
1      Status2 , Rule_name(1:len)
508      Format (
1 'C' , / ,
1 '      If ( ' , / ,
1 '      1 ( .not. ' , A , '_fired ) .and. ' , / ,
1 '      1 ( ' , A , '_stat .eq. OK ) .and. ' , / ,
1 '      1 ( ' , A , '_value ' , A4 , '' , F12.5 , ' ) .and. ' , / ,
1 '      1 ( ' , A , '_value ' , A4 , '' , F12.5 , ' ) ' , / ,
1 '      1 ) Then ' , / ,
25      ' , A , '_stat = ''', A25 ,'''', / ,
1 'd      Write(6,*)' , A , '_stat is ' , A ,'''', / ,
1 '      ' , A , '_fired = .True.' , / ,
1 '      This_pass_fires = This_pass_fires + 1' , / ,
1 'End If'
1 )
30      End If
C
35      If ( Status4 .ne. ' ' ) Then
C
40      Write( code_lun , 509 ) (Rule_name(1:len),j=1,3) , Log_op4 , Limit4 ,
1      Rule_name(1:len) , Log_op5 , Limit5 ,
1      Rule_name(1:len) , Status4 , Rule_name(1:len) ,
1      Status4 , Rule_name(1:len)
509      Format (
1 'C' , / ,
1 '      If ( ' , / ,
1 '      1 ( .not. ' , A , '_fired ) .and. ' , / ,
1 '      1 ( ' , A , '_stat .eq. OK ) .and. ' , / ,
1 '      1 ( ' , A , '_value ' , A4 , '' , F12.5 , ' ) .and. ' , / ,
1 '      1 ( ' , A , '_value ' , A4 , '' , F12.5 , ' ) ' , / ,
1 '      1 ) Then ' , / ,
1 '      ' , A , '_stat = ''', A25 ,'''', / ,
1 'd      Write(6,*)' , A , '_stat is ' , A ,'''', / ,
1 '      ' , A , '_fired = .True.' , / ,
1 '      This_pass_fires = This_pass_fires + 1' , / ,
1 'End If'
1 )
55      End If

```

```

C
5      If ( Status6 .ne. '                                ' ) Then
C
C
6      Write( code_lun , 511 ) (Rule_name(1:len),j=1,3) , Log_op6 , Limit6 ,
1        Rule_name(1:len) , Log_op7 , Limit7 ,
1        Rule_name(1:len) , Status6 , Rule_name(1:len) ,
1        Status6 , Rule_name(1:len)
10     Format (
1        'C' , / ,
1        'If ( ' , / ,
1        ' 1  ( .not. ' , A , '_fired ) .and. ' , / ,
1        ' 1  ( ' , A , '_stat .eq. OK ) .and. ' , / ,
14      ' 1  ( ' , A , '_value ' , A4 , ' ' , F12.5 , ' ) .and.' , / ,
14      ' 1  ( ' , A , '_value ' , A4 , ' ' , F12.5 , ' ) ' , / ,
14      ' 1  ) Then ' , / ,
14      ' , A , '_stat = '' , A25 , ' ' ' , / ,
14      'd      Write(6,* ) '' , A , '_stat is ' , A , ' ' ' , / ,
14      ' , A , '_fired = .True.' , / ,
14      '      This_pass_fires = This_pass_fires + 1' , / ,
14      'End If'
14
14      End If
25
C
25      Go To 502
C
30      600      Continue
C
C...Write out calculation rule code
C
35      Call Write_calc_rules
C
C...Write out analysis rule code
C
35      First = .True.
C
40      602      Continue
C
C..Read A rule
C
45      Call Read_anal_rule_params ( First , No_more )
45      If ( No_more ) Go To 700
C
C
50      Call Str$Trim ( An_cond_name , An_cond_name , Len )
50      Call Str$Trim ( An_rule_name , An_rule_name , lLen )
50      Write ( Code_lun , 699 ) (An_rule_name(1:lLen),j=1,2)
699     Format (
1        'C' , / ,
1        'C....' , A , ' Rules ' , / ,
1        'C' , / .
55

```

```

5      If ( ' / ,
5      |  (.not. ' , A , '_fired ) .and. '
5      |  )
5
C      If ( An_rule1 .ne. ' ' ) Then
5      |  Call Str$Trim ( An_rule1 , An_rule1 , Len )
10     C
10      If ( An_not1 .eq. '.NOT.' ) Then
10      |  Write( code_lun , 1001 ) An_rule1(1:Len)
10      End If
15      1001 Format (
15      |  |  (.not. ( ' , A , '_stat .EQ. Unknown ) ) .and. '
15      |  )
15      Write( code_lun , 608 ) An_not1 , An_rule1(1:Len) ,
15      |  An_status1
20      608 Format (
20      |  |  ( ' , A , ' ( ' , A , '_stat .EQ. ' ' , A , ' ' ) ) .and. '
20
25      |  )
25      End If
C
25      If ( An_rule2 .ne. ' ' ) Then
25      |  Call Str$Trim ( An_rule2 , An_rule2 , Len )
C
30      If ( An_not2 .eq. '.NOT.' ) Then
30      |  Write( code_lun , 1001 ) An_rule2(1:Len)
30      End If
30      Write( code_lun , 609 ) An_not2 , An_rule2(1:Len) ,
30      |  An_status2
35      609 Format (
35      |  |  ( ' , A , ' ( ' , A , '_stat .EQ. ' ' , A , ' ' ) ) .and. '
35
35      |  )
35      End If
C
40      If ( An_rule3 .ne. ' ' ) Then
40      |  Call Str$Trim ( An_rule3 , An_rule3 , Len )
C
45      If ( An_not3 .eq. '.NOT.' ) Then
45      |  Write( code_lun , 1001 ) An_rule3(1:Len)
45      End If
45      Write( code_lun , 610 ) An_not3 , An_rule3(1:Len) ,
45      |  An_status3
50      610 Format (
50      |  |  ( ' , A , ' ( ' , A , '_stat .EQ. ' ' , A , ' ' ) ) .and. '
50
50      |  )
50      End If
C
55      If ( An_rule4 .ne. ' ' ) Then

```

```

        Call Str$Trim ( An_rule4 , An_rule4 , Len )
C
5       If ( An_not4 .eq. 'NOT.' ) Then
          Write( code_lun , 1001 ) An_rule4(1:Len)
        End If
        Write( code_lun , 611 ) An_not4 , An_rule4(1:Len) ,
1       An_status4
10      611  Format (
1 '      1  (' , A , ' ( ' , A , '_stat .EQ. ''' , A , ''') ) .and.'
1 )
15      End If
C
16      If ( An_rule5 .ne. ' ') Then
          Call Str$Trim ( An_rule5 , An_rule5 , Len )
C
20      If ( An_not5 .eq. 'NOT.' ) Then
          Write( code_lun , 1001 ) An_rule5(1:Len)
        End If
        Write( code_lun , 612 ) An_not5 , An_rule5(1:Len) ,
25      1       An_status5
       612  Format (
1 '      1  (' , A , ' ( ' , A , '_stat .EQ. ''' , A , ''') ) .and.'
1 )
30      End If
C
31      Call Str$Trim ( An_cond_name , An_cond_name , Len )
        Write ( Code_lun , 613 )
35      1 (An_cond_name(1:Len),j=1,1) , An_end_status ,
1 (An_cond_name(1:Len),j=1,1) , An_end_status ,
1 (An_rule_name(1:Len),j=1,1)
       613  Format (
1 '      1  ( .True. ) ' , / ,
1 '      1  ) Then ' , / ,
1 '      ' , A , '_stat = ''' , A25 , '''' , / ,
1 'd      Write(6,*)''' , A , '_stat is ' , A , '''' , / ,
1 '      This_pass_fires = This_pass_fires + 1' , / ,
1 '      End If'
1 )
C
40      Go To .602
C
50      700  Continue
C
C
55      C...Write out action rule code
C
       First = .True.
C

```

```

702 Continue
C
C..Read A rule
C
5      Call Read_action_rule_params ( First , No_more )
      If ( No_more ) Go To 800
C
10     C
      Call Str$trim ( Ac_rule_name , Ac_rule_name , Len )
      Write ( Code_lun , 799 ) (Ac_rule_name(1:Len),j=1,2)
      Format (
15     1 'C' , '/',
     1 'C....' , A , ' Rules ' , '/',
     1 'C' , '/',
     1 '      If ( ' , '/',
     1 '      1   ( .not. ' , A , '_fired ) .and. '
20     1 )
C
      Call Str$trim ( Ac_rule1 , Ac_rule1 , Len )
C
25     Write( code_lun , 708 ) Ac_rule1(1:Len),
     1     Ac_status1
      Format (
28     1 '      1   ( ' , ' ( ' , A , '_stat .EO. ' ' , A , ' ' ) ) '
     1 )
C
30     C
      Call Str$trim ( Ac_rule_name , Ac_rule_name , Len )
      Write ( Code_lun , 713 ) (Ac_rule_name(1:Len),j=1,2)
      Format (
35     1 '      1   ) Then ' , '/',
     1 'd      Write(6,*) ' 'Doing action rule ' , A , ' ' ' , '/',
     1 '      ' , A , '_fired = .True.' , '/',
     1 '      This_pass_fires = This_pass_fires + 1'
     1 )
C
40     Call Str$trim ( Ac_data_line , Ac_data_line , Len )
      If ( Iac_type .eq. Exec_fort_statement ) Then
        Write ( code_lun , 714 ) Ac_data_line(1:Len)
45     714     Format (
48     1 '      ' , A
     1 )
      Else If ( Iac_type .eq. Exec_dcl_procedure ) Then
        Subprocess_name(1:sp:14) = Ac_rule_name
        Call Str$trim ( Subprocess_name , Subprocess_name , ILen )
        Write ( code_lun , 715 ) Ac_data_line(1:Len),
     1             Subprocess_name(1:ILen)
55     715     Format (
58     1 '      Call Lib$spawn ( "'@' , A , ' ' , ' ' , ' ' , A , ' ' ' ' ' ' ) '
     1 )

```

```

5
Else If ( Iac_type .eq. Send_vaxmail_msg ) Then
  Call Str$trim ( Ac_rule_name , Ac_rule_name , Len ,
  Call Str$trim ( Directory , Directory , L_dir )
    Subprocess_name(L_sp:14) = Ac_rule_name
    Call Str$trim ( Subprocess_name , Subprocess_name , !Len )
    Write(Code_lun , 788 )
    Format (
10      1 '      If ( Mode .eq. Jpi$K_other ) Then'
      1 )
      Write ( code_lun , 718 ) Directory(1:L_dir) ,
      1           Ac_rule_name(1:Len) ,
      1           Subprocess_name(1:Len)
15      718     Format (
      1 '      Call Lib$spawn ( ''2' , A , A , '.mailmsg' ,,, '' , A , '' ,,
      1 '      ,,, )'
      1 )
      Write(Code_lun , 787 )
20      787     Format (
      1 '      Else if ( Mode .eq. Jpi$K_interactive ) Then'
      1 )
      Write ( Code_lun , 789 ) Directory(1:L_dir) ,
25      1           Ac_rule_name(1:Len) , Next_label, Next_label
      Next_label = Next_label + 1
      789     Format (
      1 '      Open(11,File='' , A , A , '.mailmsg' ,Status='old'),/
      1 '      Do J = 1,3' ,/,
      1 '          Read ( 11 , ''(A)'') Line' ,/,
      1 '          End Do' ,/,
      1 '          Do J = 1,60' ,/,
      1 '              Read (11 , ''(A)'', End = 1, 14 , + ) Line' ,/,
30      1 '              Write(6,") Line'" ,/
      1 '              End Do' ,/,
      1 '          Continue' ,/,
      1 '          Close ( 11 ) '
      1 )
      Write(Code_lun , 786 )
40      786     Format (
      1 '      End If'
      1 )
45      C
      Else
        Write ( code_lun , 716 )
      716     Format (
      1 '      Write(6,") ''Bad Action type.''''
      1 )
      End If
      C
      Write ( Code_lun , 717 )
      717     Format (
      1 '      End If'
55

```

```

      1 )
C
5      Go To 702
C
800  Continue
C
10     Write( Code_lun , 9998 )
9998  Format (
      1 'd   Write(6,*)
      1 '      This_pass_fires,'' rules fired this pass.'', / ,
      1 '      If ( This_pass_fires .gt. 0 ) Go To 1' , / ,
      1 'C' , / ,
      1 '      Return' , / ,
      1 '
      1 )
      Call FdvsPutl(' Generating Expert System code.... Done.')
      Return
20     End

```

25 [0351] Thus, steps such as those listed above will produce (in this example) FORTRAN source code which defines an expert system including rules as defined by the user. This source code can then be compiled and linked, as described above, to provide an expert procedure which is callable at run-time. This expert procedure is tied into the supervisor procedure, as described above, by inserting an appropriate call into the user program section of one of the blocks in the supervisor procedure. Thus, the expert procedure can be called under specific circumstances (e.g. if selection among several possible manipulated variables must be made), or may optionally be called on every pass of the base cycle procedure, or at fixed time intervals, or according to any of the other options set forth above.

30 [0352] As will be recognized by those skilled in the art, the novel concepts described in the present application can be modified and varied over a tremendous range of applications, and accordingly their scope is not limited except by the allowed claims.

35

#### Claims

1. A computer-based method for operating a substantially continuous process (160), comprising the steps of:

40 (i) operating the process (160) with one or more sensors (156) arranged to sense conditions in the process, and one or more actuators (158) arranged to change conditions in the process (160);  
 (ii) controlling one or more of said actuators (158) with a process controller (154) in accordance with signals received from one or more of said sensors and in accordance with one or more control parameters; and  
 45 (iii) running a process supervisor procedure (130) for supervising the operation of said controlling step by selectively defining one or more of said control parameters in dependence upon data received indirectly and/or directly from said process;

50 characterised by providing a plurality of expert subprocedures (120), each for performing a respective different expert task relating to the process using a knowledge base and inference structure relevant to the process, and for outputting expert advice data; and in that

55 said process supervisor procedure (130) runs independently of said controlling step and uses a plurality of substantially self-contained software modules, each module defining a procedure for performing a desired task, and wherein said process supervisor procedure is arranged to call, under predefined conditions, said expert subprocedures (120) which output said expert advice data for use by said supervisor procedure in selectively defining said one or more control parameters.

2. The method of claim 1, wherein said knowledge base and inference structure run a substantially real-time expert

control procedure.

3. The method of claim 1, wherein said actuators (158) are controlled substantially continuously in real time, and wherein one or more of said plurality of expert subprocedures are not run continuously in real time.
4. The method of claim 1, wherein said process controller (154) uses real time logic, and wherein one or more of said plurality of expert subprocedures (120) are recurrently run as a batch process.
5. The method of any of claims 1 to 4, wherein said process controller (154) uses analog logic for controlling said actuators (158).
6. The method of any preceding claim, wherein at least one of said control parameters comprise a goal of said process controller (154).
7. The method of any preceding claim, wherein said process controller (154) comprises a computer system on which said process supervisor procedure is run.
8. The method of any preceding claim, wherein said process controller (154) and said process supervisor procedure (130) are part of the same software system.
9. The method of any preceding claim, including selectively presenting to a user a functional structure for a new rule for a selected one of said expert subprocedures (120) and/or a functional structure corresponding to the user input from which a current version of said expert subprocedure (120) was generated, and selectively compiling one or more user inputs from said functional structure into a new version of said selected expert subprocedure (120).
10. The method of claim 9, wherein said functional structure for said expert subprocedure (120) includes standardised data interface definitions such that the user can specify data having one of plural pre-defined temporal characteristics.
11. The method of claim 9 or 10, wherein said functional structure for said expert subprocedure (120) uses a substantially natural language format.
12. The method of claim 10 or 11, wherein said functional structure for said expert subprocedure (120) uses a substantially natural language format which is readily understandable by a user who is technically skilled in a predetermined art but who is not necessarily competent in any computer language.
13. The method of any of claims 9 to 12, wherein said functional structure for said expert subprocedure (120) includes user-alterable portions which appear differently to said user than do other portions of said functional structure.
14. The method of any of claims 9 to 12, wherein only restricted portions of said functional structure for said expert subprocedure (120) allow for user alterability.
15. The method of claim 14, wherein said user-alterable portions of said functional structures appear differently to said user than do other portions of said functional structures.
16. The method of any preceding claim, including selectively presenting functional structures, to a user, for a new software module for said process supervisor procedure (130) and/or a functional structure corresponding to a user input from which a current software module of said process supervisor procedure (130) was generated, and selectively loading the user input from said functional structure to be used by said process supervisor procedure (130).
17. The method of claim 16, wherein respective data definitions comprise the step of defining said one or more software modules including pointers to procedures which will carry out a respective function, and, for at least some of said software modules, parameters to be passed to said procedures pointed to.
18. The method of claim 16, wherein respective data definitions comprise the step of defining said one or more software modules including pointers to procedures which will carry out a respective function, wherein most of said procedures pointed to correspond generally to one of a limited number of procedure types, and wherein at least some of said procedures pointed to also contain further pointers to procedures which do not correspond generally to any

one of said limited number of procedure types, and, for at least some of said software modules, parameters to be passed to said procedures pointed to.

5        19. The method of any preceding claim, including using an historical database (140) containing at least one time-stamped data regarding the process, wherein said supervisor procedure (130) or said expert subprocedure (120) fetch at least one value from said historical database (140).

10      20. A method according to any preceding claim, wherein said control parameters indicate a respective threshold, wherein attainment of said threshold as indicated by signals from said one or more sensors (156) creates an indicia for action and wherein said process supervisor procedure (130) is constrained not to make changes to said control parameters unless the indicia for action has been created.

15      21. The method according to any preceding claim, wherein said process supervisor procedure (130) reports every instance where it changes a control parameter.

20      22. A method for building an expert subprocedure (120) in a method according to any preceding claim comprising the steps of:

            providing to a user functional structures, for rules according to a limited set of predetermined types, in a format which is readily understandable by a user who is not necessarily competent in any computer language, and which is not readily user alterable except in restricted portions thereof; and

            translating user inputs in accordance with said functional structures into a complete executable set of rules which defines said expert subprocedure.

25      23. A method for building an expert subprocedure in a method according to any of claims 1 to 21, comprising the steps of:

            translating user inputs in accordance with predetermined functional structures into an executable set of rules which defines an expert subprocedure;

30      wherein said functional structures provide for only three different rule types, consisting of:

            retrieval rules, respective ones thereof including standards for associating an attribute with an object selectively in accordance with input values;

            analysis rules, respective ones thereof comprising logic for associating an attribute with an object selectively in accordance with attribute/objects associations defined by other ones of said rules; and

35      action rules, respective ones thereof comprising logic for selectively executing an external command in accordance with object/attribute associations made by other ones of said rule types.

40      24. A computer-based apparatus for controlling a substantially continuous process (160), comprising:

            (a) one or more sensors (156) for sensing conditions in the process (160), and one or more actuators (158) for changing conditions in the process (160);

            (b) a process controller (154) for controlling one or more of said actuators (158) in accordance with sense data generated by at least one of said sensors (156) and in accordance with respective control parameters; and

45      (c) process supervisor means (130) arranged to receive data indirectly and/or directly from said process and operable for supervising the operation of said process controller by selectively defining one or more of said control parameters in dependence upon said received data;

50      characterised in that a plurality of expert subprocedure means (120) are provided, each for performing a respective different expert task relating to the process using a knowledge base and inference structure relevant to the process and for outputting expert advice data; and in that

55      said process supervisor means (130) is operable independently of said process controller (154) and comprises: (i) a plurality of substantially self-contained software modules, each module defining a procedure for performing a desired task; and (ii) means for calling, under predefined conditions, at least one of said plurality of expert subprocedure means which outputs said expert advice data for use by said process supervisor means (130) in selectively defining said one or more control parameters.

60      25. The apparatus of claim 24, wherein said process supervisor means (130) has a maximum iteration period significantly longer than the maximum iteration period of said process controller.

26. The apparatus of claim 24 or claim 25, including an historical database (140) containing at least one time-stamped data regarding the process.

27. The apparatus of claim 24, 25 or 26, wherein said process supervisor means (130) uses a batch process including a timed dormant state, and the duration of said dormant state is sufficiently large that said batch process does not on average occupy more than 50% of the available CPU time of the computer on which said process supervisor means (130) is run; and wherein the duration of said dormant state is selected to be sufficiently short that process fluctuations cannot diverge to an out-of-control situation during the periods when said batch process is dormant.

28. The apparatus of claim 24, 25 or 26, wherein said process controller (154) operates substantially continuously in real time, and wherein one or more of said expert subprocedure means (120) do not operate continuously in real time.

29. The apparatus of claim 24, 25 or 26, wherein said process controlled comprises real-time logic, and wherein one or more of said expert subprocedure means (120) are recurrently run as batch processes.

30. The apparatus of any of claims 24 to 29, wherein said plurality of expert subprocedure means (120) are configured as a computer running one or more programs, including a cycling process which repeatedly samples a plurality of signals corresponding to inputs, forms inferences from said inputs according to a stored knowledge base, and provides outputs in accordance with said inferences, and then goes into a dormant state which has a predetermined duration sufficiently large that said process does not on average occupy more than 50% of the available CPU time of the computer and sufficiently short that process fluctuations cannot diverge to an out-of-control situation during the periods when said expert subprocedure means are dormant.

31. The apparatus of any of claims 24 to 30, wherein said process controller (154) comprises an analog controller.

32. The apparatus of any of claims 24 to 31, wherein one or more of said control parameters is a goal of said process controller (154).

33. The apparatus of any of claims 24 to 32, wherein said process controller (154) and said process supervisor means (130) comprise processes running on the same computer system.

34. The apparatus of any of claims 24 to 33, wherein said process controller (154) and said process supervisor means (130) are both respective parts of the same software system.

35. The apparatus of any of claims 24 to 34, wherein said plurality of software modules are defined by respective data definitions, including pointers to first means for carrying out a respective function, and, for at least some of said software modules, parameters to be passed to said first means pointed to.

36. The apparatus of any of claims 24 to 34, wherein said plurality of software modules are defined by respective data definitions, including pointers to first means for carrying out a respective function, wherein most of said first means pointed to correspond generally to one of a limited number of procedure types, and wherein at least some of said first means pointed to also contain further pointers to second means which do not correspond generally to any of said limited number of procedure types, and, for at least some of said software modules, parameters to be passed to said first means pointed to.

37. The apparatus of any of claims 24 to 36, including build-expert means (110) which is configured to:

50 (i) upon command, selectively present to a user a functional structure for a new rule for a selected one of said expert subprocedure means (120);  
(ii) upon command, selectively present to a user a functional structure corresponding to the user input from which a current version of said expert subprocedure means (120) was generated;  
(iii) and selectively to compile one or more user inputs from said functional structure into a new version of said selected expert subprocedure means (120).

55 38. The apparatus of claim 37, wherein said functional structure presented to the user has a substantially natural language format which is readily understandable by a user who is technically skilled in a predetermined art but who is not necessarily competent in any computer language.

39. The apparatus of claim 37 or 38, wherein only restricted portions of said functional structure are user-alterable.

40. The apparatus of any of claims 37 to 39, wherein said functional structure comprises user-alterable portions which appear differently to said user than do other portions of said functional structure.

5 41. The apparatus of any of claims 37 to 40, wherein said functional structure uses standardised data interface definitions such that the user can specify data having one of plural pre-defined temporal characteristics.

10 42. The apparatus of any of claims 24 to 41, including build-supervisor means (810) which is configured to:

(i) upon command, selectively present to a user a functional structure for a new software module for said process supervisor means (130);  
 (ii) upon command, present to a user a functional structure corresponding to a user input from which a current software module of said process supervisor means (130) was generated;  
 15 (iii) and selectively to load the user input from said functional structure to be used by said process supervisor means (130).

43. The apparatus of claim 42, wherein said build-supervisor means (810) does not allow data corresponding to fresh user inputs to become actively accessed by said process supervisor means (130) until a validation run has been 20 performed.

44. The apparatus of claims 42 or 43, wherein said process supervisor (130) means uses means for cycling and said process controller (154) runs substantially in real-time.

25 45. The apparatus of any of claims 24 to 44, wherein said knowledge base and inference structure define a substantially real-time expert control system (120).

46. The apparatus of any of claims 24 to 44, wherein said process controller (154) operates substantially continuously 30 in real time, and wherein one or more of said expert subprocedure means (120) do not operate continuously in real time.

47. The apparatus according to any of claims 24 to 44, wherein one or more of said expert subprocedure means (120) comprises:

35 a collection of inference rules, consisting of retrieval rules, respective ones thereof including standards for associating an attribute with an object selectively in accordance with input values; analysis rules, respective ones thereof comprising logic for associating an attribute with an object selectively in accordance with one or more other attributes associated with objects by others of said rules; action rules, respective ones thereof comprising logic for executing an external command selectively in accordance with one or more other attributes associates with objects by others of said rules; 40 a processor connected to receive inputs from an input channel, to execute said collection of inference rules on said inputs, and to provide outputs on an output channel accordingly, wherein said processor is not connected to perform any purely arithmetic test while executing said analysis rules nor while executing said action rules; 45 and wherein said processor is not connected to evaluate any logical expression having three or more input terms while executing said action rules.

48. An apparatus for building an expert subprocedure means (120) in an apparatus according to any of claims 24 to 47, comprising:

50 rule generation logic, which, when activated, provides to a user, via an interactive interface, templates for at least three different rule types, including:  
 retrieval rules, respective ones thereof including standards for associating an attribute with an object selectively in accordance with input values;  
 55 analysis rules, respective ones thereof comprising logic for associating an attribute with an object selectively in accordance with other object/attribute associations; and action rules, respective ones thereof comprising logic for executing an external command selectively in accordance with other object/attribute associations;

wherein said respective rules are presented to the user as templates which have a format which is readily understandable by a user who is not necessarily competent in any computer language;  
wherein only restricted portions of said templates are user-alterable;  
and wherein said rule generation of logic translates user inputs in accordance with said templates into an executable set of rules which define said expert subprocedure means (120).

5 49. An apparatus for building an expert system in an apparatus according to any of claims 24 to 47, comprising:  
rule generation logic, which when activated provides to a user functional structures for rules according to a limited set of predetermined types, wherein said rule generator logic presents said functional structures for all of said rules in a format which is readily understandable by a user who is not necessarily competent in any computer language, and which is not user-alterable except in restricted portions thereof; and wherein said rule generation logic translates user inputs in accordance with said functional structures into a complete executable set of rules which defines said expert subprocedure means (120).

15 **Patentansprüche**

1 1. Computerbasiertes Verfahren zum Betrieb eines im wesentlichen kontinuierlichen Prozesses (160) mit den Schritten:

20 (i) Betrieb des Prozesses (160) mit einem oder mehreren Sensoren (156), die zum Erfassen von Bedingungen des Prozesses angeordnet sind, und mit einem oder mehreren Stellgliedern (158), die zur Änderung der Bedingungen im Prozeß (160) angeordnet sind;  
(ii) Steuern des einen oder der mehreren Stellglieder (158) mit einer Prozeßsteuerung (154) in Übereinstimmung mit Signalen, die von dem einen oder mehreren der Sensoren empfangen werden, und in Übereinstimmung mit einem oder mehreren Steuerparametern; und  
(iii) Durchführen einer Prozeßüberwachungsprozedur (130) zur Überwachung des Betriebs des Steuerschritts durch selektives Festlegen eines oder mehrerer der Steuerparameter in Abhängigkeit von Daten, die indirekt und/oder direkt von dem Prozeß erhalten werden;

30 gekennzeichnet durch Vorsehen einer Mehrzahl von Expertenunterprozeduren (120), jeweils zur Durchführung einer jeweiligen unterschiedlichen Expertenaufgabe bezüglich des Prozesses unter Verwendung einer Wissensdatenbank und einer Verknüpfungsstruktur bezüglich des Prozesses, und zur Ausgabe von Expertenanweisungsdaten; und dadurch, daß

35 die Prozeßüberwachungsprozedur (130) unabhängig von dem Steuerschritt läuft und eine Mehrzahl von im wesentlichen selbstenthaltenden Softwaremodulen verwendet, wobei jedes Modul eine Prozedur zur Durchführung einer gewünschten Aufgabe festlegt und wobei die Prozeßüberwachungsprozedur angeordnet ist, um unter vorgegebenen Bedingungen die Expertenunterprozeduren (120) aufzurufen, die die Expertenanweisungsdaten für die Verwendung durch die Überwachungsprozedur beim selektiven Festlegen des einen oder der mehreren Steuerparameter ausgeben.

40 2. Verfahren nach Anspruch 1, bei dem die Wissensdatenbank und die Verknüpfungsstruktur im wesentlichen in Echtzeit eine Expertensteuerprozedur durchführen.

45 3. Verfahren nach Anspruch 1, bei dem die Stellglieder (158) im wesentlichen kontinuierlich in Echtzeit gesteuert werden und bei dem eine oder mehrere der Expertenunterprozeduren nicht kontinuierlich in Echtzeit laufen.

50 4. Verfahren nach Anspruch 1, bei dem die Prozeßsteuerung (154) eine Echtzeitlogik verwendet und bei dem eine oder mehrere der Expertenunterprozeduren (120) periodisch als ein Stapelprozeß durchgeführt werden.

55 5. Verfahren nach einem der Ansprüche 1 bis 4, bei dem die Prozeßsteuerung (154) eine analoge Logik zur Steuerung der Stellglieder (158) verwendet.

6. Verfahren nach einem der vorangehenden Ansprüche, bei dem zumindest einer der Steuerparameter ein Ziel der Prozeßsteuerung (154) umfaßt.

55 7. Verfahren nach einem der vorangehenden Ansprüche, bei dem die Prozeßsteuerung (154) ein Computersystem umfaßt, auf dem die Prozeßüberwachungsprozedur läuft.

8. Verfahren nach einem der vorangehenden Ansprüche, bei dem die Prozeßsteuerung (154) und die Prozeßüberwachungsprozedur (130) Teil des gleichen Softwaresystems sind.

5 9. Verfahren nach einem der vorangehenden Ansprüche, das einschließt: selektives Präsentieren für einen Benutzer einer Funktionalstruktur für eine neue Regel für eine ausgewählte Expertenunterprozedur (120) und/oder einer Funktionalstruktur entsprechend einer Benutzereingabe, aus der die laufende Version der Expertenunterprozedur (120) erzeugt werden, und selektive Kompilieren einer oder mehrerer Benutzereingaben aus der Funktionalstruktur in eine neue Version der ausgewählten Expertenunterprozedur (120).

10 10. Verfahren nach Anspruch 9, bei dem die Funktionalstruktur der Expertenunterprozedur (120) standardisierte Datenschnittstellendefinitionen enthält, so daß der Benutzer Daten mit einer Mehrzahl vorgegebener temporärer Charakteristika spezifizieren kann.

15 11. Verfahren nach Anspruch 9 oder 10, bei dem die Funktionalstruktur für die Expertenunterprozedur (120) ein Format im wesentlichen in natürlicher Sprache verwendet.

12. Verfahren nach den Ansprüchen 10 oder 11, bei dem die Funktionalstruktur für die Expertenunterprozedur (120) ein Format im wesentlichen in natürlicher Sprache verwendet, das für einen Benutzer mit technischer Ausbildung auf einem vorgegebenen Gebiet, der nicht notwendigerweise in einer Computersprache geschult ist, leicht verständlich ist.

20 13. Verfahren nach einem der Ansprüche 9 bis 12, bei dem die Funktionalstruktur für die Expertenunterprozedur (120) vom Benutzer abänderbare Abschnitte enthält, die dem Benutzer unterschiedlich zu anderen Abschnitten der Funktionalstruktur angezeigt werden.

25 14. Verfahren nach einem der Ansprüche 9 bis 12, bei dem nur vorgegebene Abschnitte der Funktionalstruktur der Expertenunterprozedur (120) die Änderung durch den Benutzer ermöglichen.

15. Verfahren nach Anspruch 14, bei dem die vom Benutzer zu ändernden Abschnitte der Funktionalstruktur dem Benutzer anders als die anderen Abschnitte der Funktionalstruktur dargestellt sind.

30 16. Verfahren nach einem der vorangehenden Ansprüche, das einschließt:  
selektives Darstellen für einen Benutzer der Funktionalstrukturen für ein neues Softwaremodul für die Prozeßüberwachungsprozedur (130) und/oder einer Funktionalstruktur entsprechend einer Benutzereingabe, aus der ein laufendes Softwaremodul der Prozeßüberwachungsprozedur (130) erzeugt wurde, und selektives Laden der Benutzereingabe aus der Funktionalstruktur zur Verwendung durch die Prozeßüberwachungsprozedur (130).

35 17. Verfahren nach Anspruch 16, bei dem jeweilige Datendefinitionen enthalten: den Schritt des Festlegens des einen oder mehrerer Softwaremodule, einschließlich Zeiger zu Prozeduren, die eine jeweilige Funktion ausführen werden, und zumindest für einige der Softwaremodule Parameter, die an die angezeigten Prozeduren weiterzuleiten sind.

40 18. Verfahren nach Anspruch 16, bei dem jeweilige Datendefinitionen umfassen: den Schritt des Festlegens des einen oder mehrerer Softwaremodule, einschließlich Zeiger zu Prozeduren, die eine jeweilige Funktion ausführen werden, wobei die meisten der angezeigten Prozeduren im allgemeinen einem Typ eines bekannten Satzes von Prozedurtypen entsprechen und wobei zumindest einige der angezeigten Prozeduren auch weitere Zeiger zu Prozeduren enthalten, die nicht allgemein einer der begrenzten Zahl von Prozedurtypen entsprechen, und für zumindest einige der Softwaremodule Parameter, die an diese gezeigte Prozeduren weiterzuleiten sind.

45 19. Verfahren nach einem der vorangehenden Ansprüche, das die Verwendung einer historischen Datenbank (140) einschließt, die zumindest ein Zeitmarkendatum bezüglich des Prozesses enthält, wobei die Überwachungsprozedur (130) oder die Expertenunterprozedur (120) zumindest einen Wert aus der historischen Datenbank (140) holt.

50 20. Verfahren nach einem der vorangehenden Ansprüche, bei dem die Steuerparameter einen jeweiligen Schwellenwert anzeigen, wobei das von den Signalen des einen oder der mehreren Sensoren (156) angezeigte Erreichen des Schwellenwerts ein Anzeichen für eine Handlung erzeugt und wobei die Prozeßüberwachungsprozedur (130) so eingeschränkt ist, daß sie keine Änderung der Steuerparameter vornimmt, falls nicht das Anzeichen für eine

Handlung erzeugt wurde.

21. Verfahren nach einem der vorangehende Ansprüche, bei dem die Prozeßüberwachungsprozedur (130) jedesmal berichtet, wenn ein Steuerparameter geändert wird.

5

22. Verfahren zur Ausbildung einer Expertenunterprozedur (120) in einem Verfahren nach einem der vorangehenden Ansprüche mit den Schritten:

10 Vorsehen einer Benutzerfunktionalstruktur für Regeln entsprechend einem begrenzten Satz von vorgegebenen Typen in einem Format, das leicht von einem Benutzer zu verstehen ist, der nicht notwendigerweise in irgendeiner Computersprache geschult ist, und die mit Ausnahme von beschränkten Abschnitten nicht einfach vom Benutzer geändert werden kann, und  
Übersetzen der Benutzereingaben in Übereinstimmung mit der Funktionalstruktur in einen vollständig ausführbaren Satz von Regeln, die die Expertenunterprozedur festlegen.

15

23. Verfahren zur Ausbildung einer Expertenunterprozedur in einem Verfahren nach einem der Ansprüche 1 bis 21 mit den Schritten:

20 Übersetzen der Benutzereingaben in Übereinstimmung mit vorgegebenen Funktionalstrukturen in einen ausführbaren Satz von Regeln, die eine Expertenunterprozedur festlegen;  
wobei die Funktionalstrukturen nur drei verschiedene Regeltypen vorsehen, bestehend aus:  
Wiederherstellungsregeln, von denen einige Standards einschließen, die selektiv ein Attribut mit einem Objekt in Übereinstimmung mit Eingabewerten assoziieren;  
25 Analyseregeln, von denen einige eine Logik einschließen, die selektiv ein Attribut mit einem Objekt in Übereinstimmung mit Attribut/Objekt-Assoziationen, die von anderen Regeln festgelegt sind, assoziieren; und  
Handlungsregeln, von denen einige eine Logik zur selektiven Ausführung eines externen Befehls in Übereinstimmung mit Objekt/Attribut-Assoziationen enthalten, die von anderen der Regeltypen vorgenommen wurden.

30 24. Computerbasierte Vorrichtung zur Steuerung eines im wesentlichen kontinuierlichen Prozesses (160) mit:

35 (a) einem oder mehreren Sensoren (156) zur Erfassung von Bedingungen in dem Prozeß (160) und einem oder mehreren Stellgliedern (158) zur Änderung der Bedingungen in dem Prozeß (160);  
(b) einer Prozeßsteuerung (154) zur Steuerung eines oder mehrerer der Stellglieder (158) in Übereinstimmung mit von dem zumindest einen Sensor (156) erzeugten Sensordaten und in Übereinstimmung mit jeweiligen Steuerparametern; und  
(c) Prozeßüberwachungsmitteln (130), die zum direkten und/oder indirekten Empfang von Daten des Prozesses angeordnet und zur Überwachung des Betriebs der Prozeßsteuerung betreibbar sind, wobei selektiv einer oder mehrere der Steuerparameter in Abhängigkeit von den empfangenen Daten festgelegt werden;

40

45 dadurch **gekennzeichnet**, daß eine Mehrzahl von Expertenunterprozedurmitteln (120) vorgesehen sind, die jeweils verschiedene Expertenaufgaben bezüglich des Prozesses mit einer Wissensdatenbank und einer Verknüpfungsstruktur bezüglich des Prozesses durchführen und Expertenanweisungsdaten auszugeben, und dadurch, daß  
das Prozeßüberwachungsmittel (130) unabhängig von der Prozeßsteuerung (154) betreibbar ist und enthält:  
(i) eine Mehrzahl im wesentlichen selbstenthaltender Softwaremodule, wobei jedes Modul eine Prozedur zur Ausführung einer gewünschten Aufgabe festlegt; und (ii) Mittel zum Aufrufen unter vorgegebenen Bedingungen von zumindest einer der Expertenunterprozedurmittel, das die Expertenanweisungsdaten für die Verwendung durch das Prozeßüberwachungsmittel (130) für das selektive Festlegen des einen oder der mehreren Steuerparameter ausgibt.

50

55 25. Vorrichtung nach Anspruch 24, bei der das Prozeßüberwachungsmittel (130) eine maximale Iterationszeitspanne hat, die beachtlich länger als die maximale Iterationszeitspanne der Prozeßsteuerung ist.

26. Vorrichtung nach Anspruch 24 oder 25, mit einer historischen Datenbank (140), die zumindest ein Zeitmarkendatum bezüglich des Prozesses enthält.

27. Vorrichtung nach Anspruch 24, 25 oder 26, bei der das Prozeßüberwachungsmittel (130) einen Stapelprozeß mit

5 einem zeitgesteuerten Ruhezustand verwendet und die Dauer des Ruhezustands hinreichend lang ist, so daß der Stapelprozeß im Mittel nicht mehr als 50% der zugänglichen CPU-Zeit des Computers benutzt, auf dem das Prozeßüberwachungsmittel (130) ausgeführt wird, und wobei die Dauer des Ruhezustands so hinreichend kurz ausgewählt wird, daß die Prozeßfluktuationen während dieser Zeitspannen, in denen der Stapelprozeß in Ruhe ist, nicht in eine Situation außer Kontrolle divergieren können.

10 28. Vorrichtung nach Anspruch 24, 25 oder 26, bei der die Prozeßsteuerung (154) im wesentlichen kontinuierlich in Echtzeit arbeitet und eines oder mehrere der Expertenunterprozedurmittel (120) nicht kontinuierlich in Echtzeit arbeiten.

15 29. Vorrichtung nach Anspruch 24, 25 oder 26, bei der der gesteuerte Prozeß eine Echtzeitlogik enthält und eins oder mehrere der Expertenunterprozedurmittel (120) periodisch als Stapelprozeß laufen.

20 30. Vorrichtung nach einem der Ansprüche 24 oder 29, bei der die Mehrzahl der Expertenunterprozedurmittel (120) als ein oder mehrere Programme konfiguriert sind, die auf einem Computer laufen, einschließlich eines zyklischen Prozesses, welcher wiederholt eine Mehrzahl von Signalen entsprechend den Eingaben abtastet, die Eingaben entsprechend einer gespeicherten Wissensdatenbank verknüpft werden, und Ausgaben in Übereinstimmung mit den Verknüpfungen geliefert werden, und die dann in einen Ruhezustand geht, der eine vorgegebene Dauer hat, die hinreichend lang ist, so daß der Prozeß nicht mehr als 50% der zugänglichen CPU-Zeit des Computers einnimmt, und die hinreichend kurz ist, so daß Prozeßfluktuationen während der Zeitspannen, in denen die Expertenunterprozedurmittel in Ruhe sind, nicht zu einer Situation außer Kontrolle divergieren können.

25 31. Vorrichtung nach einem der Ansprüche 24 bis 30, bei dem die Prozeßsteuerung (154) eine Analogsteuerung enthält.

32. Vorrichtung nach einem der Ansprüche 24 bis 31, bei der einen oder mehrere der Steuerparameter ein Ziel der Prozeßsteuerung (154) sind.

30 33. Vorrichtung nach einem der Ansprüche 24 bis 32, bei der die Prozeßsteuerung (154) und das Prozeßüberwachungsmittel (130) Prozesse umfassen, die auf dem gleichen Computersystem laufen.

34. Vorrichtung nach einem der Ansprüche 24 bis 33, bei dem die Prozeßsteuerung (154) und die Prozeßüberwachungsmittel (130) jeweils Teile des gleichen Softwaresystems sind.

35 35. Vorrichtung nach einem der Ansprüche 24 bis 34, bei der die Mehrzahl der Softwaremodule durch jeweilige Datendefinitionen festgelegt sind, einschließlich Zeigern zu ersten Mitteln zur Ausführung einer jeweiligen Funktion, und - für zumindest einige der Softwaremodule - durch Parameter, die zu den angezeigten ersten Mitteln durchgeflossen werden.

40 36. Vorrichtung nach einem der Ansprüche 24 bis 34, bei der die Mehrzahl der Softwaremodule durch jeweilige Datendefinitionen festgelegt sind, einschließlich Zeigern zu ersten Mitteln zur Ausführung einer jeweiligen Funktion, wobei die meisten der angezeigten ersten Mittel im allgemeinen einem Typ eines beschränkten Satz von Prozedurtypen entsprechen, und wobei zumindest einige der angezeigten ersten Mittel auch weitere Zeiger zu zweiten Mitteln enthalten, die nicht allgemein einem Typ der angezeigten Zahl von Prozedurtypen entsprechen, und für zumindest einige der Softwaremodule Parameter, die an die ersten angezeigten Mittel weitergeleitet werden.

45 37. Vorrichtung nach einem der Ansprüche 24 bis 36 mit Aufbauexpertenmitteln (110), die ausgestaltet sind, um:

50 (i) auf Befehl selektiv einem Benutzer eine Funktionalstruktur für eine neue Regel für ein ausgewähltes Expertenunterprozedurmittel (120) zu präsentieren;  
 (ii) auf Befehl selektiv einem Benutzer eine Funktionalstruktur entsprechend der Benutzereingabe zu präsentieren, von der eine gegenwärtige Version des Expertenunterprozedurmittels (120) erzeugt wurde;  
 (iii) und selektiv eine oder mehrere Benutzereingaben aus der Funktionalstruktur in eine neue Version der ausgewählten Expertenunterprozedurmittel (120) zu kompilieren.

55 38. Vorrichtung nach Anspruch 37, bei der die dem Benutzer präsentierte Funktionalstruktur ein Format im wesentlichen in natürlicher Sprache hat, die von einem Benutzer, der auf einem vorgegebenen Gebiet technisch, aber nicht notwendigerweise bezüglich einer Computersprache, geschult ist leicht verstanden werden kann.

39. Vorrichtung nach Anspruch 37 oder 38, bei der nur beschränkte Teile der Funktionalstruktur vom Benutzer zu ändern sind.

40. Vorrichtung nach einem der Ansprüche 37 bis 39, bei der die Funktionalstruktur vom Benutzer zu ändernde Abschnitte aufweist, die dem Benutzer anders als andere Abschnitte der Funktionalstruktur dargestellt werden.

41. Vorrichtung nach einem der Ansprüche 37 bis 40, bei der die Funktionalstruktur standardisierte Datenschnittstellendefinitionen verwendet, so daß der Benutzer die Daten mittels eines oder mehrerer vorgegebener temporärer Charakteristika spezifizieren kann.

42. Vorrichtung nach einem der Ansprüche 24 bis 41, mit Aufbauüberwachungsmitteln (810), die ausgestaltet sind, um:

- (i) auf Befehl selektiv einem Benutzer eine Funktionalstruktur für ein neues Softwaremodul für das Prozeßüberwachungsmittel (130) zu präsentieren;
- (ii) auf Befehl einem Benutzer eine Funktionalstruktur entsprechend einer Benutzereingabe zupräsentieren, aus der ein gegenwärtiges Softwaremodul des Prozeßüberwachungsmittels (130) erzeugt wurde; und
- (iii) selektiv die Benutzereingabe aus der funktionalen Struktur zur Verwendung durch das Prozeßüberwachungsmittel (130) zu laden.

43. Vorrichtung nach Anspruch 42, bei der das Aufbauüberwachungsmittel (810) es nicht erlaubt, daß Daten, die frischen Benutzereingaben entsprechen, aktiv von dem Prozeßüberwachungsmittel (130) zugegriffen werden, bis ein Gültigkeitsdurchlauf durchgeführt ist.

44. Vorrichtung nach den Ansprüchen 42 oder 43, bei der das Prozeßüberwachungsmittel (130) Mittel zum zyklischen Durchlauf verwendet und wobei die Prozeßsteuerung (154) im wesentlichen in Echtzeit läuft.

45. Vorrichtung nach einem der Ansprüche 24 bis 44, bei der die Wissensdatenbank und die Verknüpfungsstruktur ein im wesentlichen Echtzeit-Expertensteuersystem (120) festlegen.

46. Vorrichtung nach einem der Ansprüche 24 bis 44, bei der die Prozeßsteuerung (154) im wesentlichen kontinuierlich in Echtzeit arbeitet und eines oder mehrere der Expertenunterprozedurmittel (120) nicht in Echtzeit arbeiten.

47. Vorrichtung nach einem der Ansprüche 24 bis 44, bei der eines oder mehrere der Expertenunterprozedurmittel (120) aufweisen:

- eine Ansammlung von Verknüpfungsregeln, die aus Wiederherstellungsregeln bestehen, von denen einige Standards für die Assozierung von Attributen selektiv mit einem Objekt in Übereinstimmung mit Eingabewerten enthalten;
- Anlyseregeln, von denen einige eine Logik zur Assozierung von Attributen selektiv mit einem Objekt in Übereinstimmung mit einem oder mehreren Attribut-Assoziationen mit Objekten durch andere der Regeln auszuführen;
- einem Prozessor, der zum Empfang von Eingaben von einem Eingabekanal geschaltet ist, um die Anwendung von Verknüpfungsregeln bezüglich der Eingaben durchzuführen und um dementsprechend Ausgaben an einen Ausgabekanal zu liefern, wobei der Prozessor nicht geschaltet wird, um reine arithmetische Tests durchzuführen, während er die Analyse regeln oder die Handlungsregeln ausführt;
- und wobei der Prozessor nicht geschaltet wird, um irgendwelche logischen Ausdrücke zu bewerten, die drei oder mehr Eingangsbegriffe haben, während er die Handlungsregeln ausführt.

48. Vorrichtung zur Ausbildung eines Expertenunterprozedurmittels (120) in einer Vorrichtung nach einem der Ansprüche 24 bis 47 mit:

- einer Regelerzeugungslogik, die bei Aktivierung durch einen Benutzer über eine interaktive Schnittstelle Schablonen für zumindest drei verschiedene Regeltypen liefert, die enthalten:
- Wiederherstellungsregeln, von denen einige Standards zur Assozierung von Attributen selektiv mit einem Objekt in Übereinstimmung mit Eingabewerten enthalten;
- Anlyseregeln, von denen einige eine Logik zur Assozierung von Attributen selektiv mit einem Objekt in Über-

5 einstimmung mit anderen Objekt/Attribut-Assoziationen enthalten; und Handlungsregeln, von denen einige eine Logik zur Ausführung eines externen Befehls selektiv in Übereinstimmung mit anderen Objekt/Attribut-Assoziationen enthalten; wobei die jeweiligen Regeln dem Benutzer als Schablone präsentiert werden, die ein Format haben, das leicht von einem Benutzer verstanden werden kann, der nicht notwendigerweise in irgendeiner Computersprache geschult ist; wobei nur beschränkte Abschnitte der Schablonen vom Benutzer änderbar sind; und wobei die Regelerzeugung der Logik Benutzereingaben in Übereinstimmung mit den Schablonen in einen ausführbaren Satz an Regeln übersetzt, die das Expertenunterprozedurmittel (120) festlegen.

10 49. Vorrichtung zur Ausbildung eines Expertensystems in einer Vorrichtung nach einem der Ansprüche 24 bis 47 mit: einer Regelerzeugungslogik, die bei Aktivierung an einen Benutzer Funktionalstrukturen für Regeln entsprechend einem beschränkten Satz an vorgegebenen Typen liefert, wobei die Regelerzeugungslogik die Funktionalstruktur für alle Regeln in einem Format präsentiert, das leicht von einem Benutzer verstanden werden kann, der nicht notwendigerweise in einer Computersprache geschult ist, und das vom Benutzer mit Ausnahme von beschränkten Abschnitten nicht geändert werden kann, und wobei die Regelerzeugungslogik die Benutzereingaben in Übereinstimmung mit der Funktionalstruktur in einen vollständig ausführbaren Satz an Regeln umsetzt, die das Expertenunterprozedurmittel (120) festlegen.

20 **Revendications**

25 1. Un procédé informatique pour l'exploitation d'un processus sensiblement continu (160), comprenant les étapes consistent :

30 (i) à exploiter le processus (160) avec un ou plusieurs capteurs (156) agencés pour capter des conditions du processus, et un ou plusieurs organes d'actionnement (158) agencés pour varier des conditions du processus (160) ;  
 (ii) à commander un ou plusieurs des organes d'actionnement (158) au moyen d'un contrôleur de processus (154) en correspondance à des signaux reçus à partir d'un ou de plusieurs capteurs et en correspondance à un ou plusieurs paramètres de commande ; et  
 (iii) à exécuter une procédure de supervision du processus (130) pour surveiller le fonctionnement de ladite étape de commande en définissant de façon sélective un ou plusieurs desdits paramètres de commande en fonction des données reçues directement et/ou indirectement dudit processus ;

35 caractérisé par la mise à disposition d'une pluralité de sous-procédures expertes (120), chacune pour exécuter une tâche experte respectivement différente concernant le processus, utilisant une base de connaissance et une structure d'inférence concernant le processus, et pour fournir en sortie des données de conseil d'expert; et en ce que

40 ladite procédure de supervision du processus (130) s'exécute indépendamment de ladite étape de commande et utilise une pluralité de modules logiciels sensiblement autonomes, chaque module définissant une procédure pour la réalisation d'une tâche souhaitée, et dans lequel ladite procédure de supervision du processus est agencée pour appeler, sous des conditions prédéfinies, lesdites sous-procédures expertes (120) qui fournissent en sortie lesdites données de conseil d'expert pour utilisation par ladite procédure de supervision dans la définition sélective desdits un ou plusieurs paramètres de commande.

45 2. Le procédé de la revendication 1, dans lequel ladite base de connaissance et la structure d'inférence exécutent une procédure de commande experte sensiblement en temps réel.

50 3. Le procédé de la revendication 1, dans lequel lesdits organes d'actionnement (158) sont commandés sensiblement en continu, en temps réel, et dans lequel une ou plusieurs de ladite pluralité de sous-procédures expertes ne s'exécutent pas en continu en temps réel.

55 4. Le procédé de la revendication 1, dans lequel ledit contrôleur de processus (154) utilise de la logique temps réel, et dans lequel une ou plusieurs de ladite pluralité de sous-procédures expertes (120) sont exécutées de façon récurrente en tant que traitement par lots.

5. Le procédé selon l'une quelconque des revendications 1 à 4, dans lequel ledit contrôleur de processus (154) utilise

de la logique analogique pour la commande desdits organes d'actionnement (158).

6. Le procédé selon l'une quelconque des revendications précédentes dans lequel au moins un desdits paramètres de commande comprend un but ou une valeur cible dudit contrôleur de processus (154).
7. Le procédé selon l'une quelconque des revendications précédentes dans lequel ledit contrôleur de processus (154) comprend un système informatique sur lequel s'exécute ladite procédure de supervision de processus.
8. Le procédé selon l'une quelconque des revendications précédentes dans lequel ledit contrôleur de processus (154) et ladite procédure de supervision de processus (130) font partie du même système logiciel.
9. Le procédé selon l'une quelconque des revendications précédentes comprenant la présentation à un utilisateur, de façon sélective, une structure fonctionnelle pour une nouvelle règle pour une sous-procédures sélectionnée parmi lesdites sous-procédures expertes (120) et/ou une structure fonctionnelle correspondant à l'entrée fournie par l'utilisateur à partir de laquelle une version actuelle de ladite sous-procédures experte (120) a été générée, et la compilation sélective d'une ou de plusieurs entrées fournies par l'utilisateur à partir de ladite structure fonctionnelle pour donner une nouvelle version de ladite sous-procédures experte (120).
10. Le procédé de la revendication 9, dans lequel ladite structure fonctionnelle pour ladite sous-procédures experte (120) comprend des définitions standardisées d'une interface de données de sorte que l'utilisateur puisse spécifier des données présentant une caractéristique parmi une pluralité de caractéristiques temporelles prédéfinies.
11. Le procédé de la revendication 9 ou 10, dans lequel ladite structure fonctionnelle pour ladite sous-procédures experte (120) utilise un format sensiblement en langage naturel.
12. Le procédé de la revendication 10 ou 11, dans lequel ladite structure fonctionnelle pour ladite sous-procédures experte (120) utilise un format sensiblement en langage naturel qui est facilement compréhensible par un utilisateur qui possède des aptitudes techniques dans un art prédéterminé mais qui n'est pas forcément compétent dans un langage informatique quelconque.
13. Le procédé selon l'une quelconque des revendications 9 à 12, dans lequel ladite structure fonctionnelle pour ladite sous-procédures experte (120) comprend des parties susceptibles d'être variées par l'utilisateur qui apparaissent différemment aux utilisateurs par rapport à d'autres parties de ladite structure fonctionnelle.
14. Le procédé selon l'une quelconque des revendications 9 à 12, dans lequel uniquement des parties limitées de ladite structure fonctionnelle pour ladite sous-procédures experte (120) permettent la possibilité de variation par l'utilisateur.
15. Le procédé de la revendication 14, dans lequel lesdites parties susceptibles d'être variées par l'utilisateur desdites structures fonctionnelles apparaissent différemment à l'utilisateur par rapport à d'autres parties desdites structures fonctionnelles.
16. Le procédé selon l'une quelconque des revendications précédentes comprenant la présentation de façon sélective de structures fonctionnelles à un utilisateur pour un nouveau module logiciel pour ladite procédure de supervision de processus (130) et/ou une structure fonctionnelle correspondante à une entrée fournie par l'utilisateur à partir de laquelle un module logiciel actuel de ladite procédure de supervision de processus (130) a été généré, et le chargement sélectif de l'entrée fournie par l'utilisateur à partir de ladite structure fonctionnelle, pour utilisation par ladite procédure de supervision de processus (130).
17. Le procédé de la revendication 16, dans lequel les définitions respectives des données comprennent l'étape consistant à définir un parmi lesdits un ou plusieurs modules logiciels comprenant des pointeurs vers des procédures qui vont effectuer une fonction respective, et, en ce qui concerne au moins certains des modules logiciels, des paramètres à passer auxdites procédures indiquées par les pointeurs.
18. Le procédé de la revendication 16, dans lequel des définitions respectives des données comprennent l'étape consistant à définir un parmi lesdits un ou plusieurs modules logiciels comprenant des pointeurs vers des procédures qui vont effectuer une fonction respective, dans lequel la plupart desdites procédures référencées par les pointeurs correspondent généralement à un parmi un nombre limité de types de procédures, et dans lequel au

moins certaines desdites procédures référencées par pointeur, contiennent également des pointeurs supplémentaires vers des procédures qui ne correspondent pas généralement à aucun parmi ledit nombre limité de types de procédure et, en ce qui concerne au moins certains desdits modules logiciels, des paramètres à passer vers lesdites procédures référencées par pointeur.

19. Le procédé selon l'une quelconque des revendications précédentes comprenant l'utilisation d'une base de données historiques (140) contenant au moins une donnée horodatée concernant le processus, dans lequel ladite procédure de supervision (130) ou ladite sous-procédure experte (120) recherche au moins une valeur à partir de ladite base de données historiques (140).
20. Un procédé selon l'une quelconque des revendications précédentes, dans lequel lesdits paramètres de commande indiquent un seuil respectif, dans lequel le fait d'avoir atteint ledit seuil, comme indiqué par des signaux à partir dudit un ou plusieurs capteurs (156) crée un indice pour des actions, et dans lequel ladite procédure de supervision de processus (130) est contrainte à ne pas effectuer des changements desdits paramètres de commande sauf dans le cas où les indices pour l'action ont été créés.
21. Le procédé selon l'une quelconque des revendications précédentes, dans lequel ladite procédure de supervision de processus (130) émet un compte-rendu à chaque fois où elle change un paramètre de commande.
22. Un procédé pour créer une sous-procédure experte (120) dans un procédé selon l'une quelconque des revendications précédentes, comprenant les étapes consistant à fournir à un utilisateur, des structures fonctionnelles, pour des règles en fonction d'un jeu limité de types prédéterminés, dans un format qui est facilement compréhensible par un utilisateur qui n'est pas forcément compétent dans un langage informatique quelconque, et qui n'est pas facilement susceptible d'être changé par l'utilisateur sauf dans des parties limitées de la structure ; et à traduire des entrées fournies par l'utilisateur en correspondance auxdites structures fonctionnelles en un jeu complet exécutable de règles qui définissent ladite sous-procédure experte.
23. Un procédé pour réaliser une sous-procédure experte dans un procédé selon l'une quelconque des revendications 1 à 21, comprenant les étapes consistant :
  - à traduire les entrées fournies par l'utilisateur en correspondance à des structures fonctionnelles prédéterminées en un jeu de règles exécutables qui définissent une sous-procédure experte ; dans lequel lesdites structures fonctionnelles n'admettent que trois différents types de règles uniquement, consistant en :
    - des règles d'extraction dont certaines comprennent respectivement des standards pour l'association d'un attribut avec un objet de façon sélective, en fonction des valeurs d'entrée ;
    - des règles d'analyse, dont certaines comprennent respectivement de la logique pour l'association d'un attribut avec un objet de façon sélective, en fonction des associations attribut/objet définies par d'autres règles parmi lesdites règles ; et
    - des règles d'action dont certaines comprennent respectivement de la logique pour l'exécution sélective d'une commande externe en fonction d'associations objet/attribut effectuées par certains autres types de règles parmi lesdits types de règles.
24. Un appareil informatique pour la commande et le contrôle d'un processus sensiblement continu (160), comprenant :
  - (a) un ou plusieurs capteurs (156) pour capter des conditions du processus (160) et un ou plusieurs organes d'actionnement (158) pour varier des conditions du processus (160) ;
  - (b) un contrôleur de processus (154) pour la commande d'un ou de plusieurs desdits organes d'actionnement (158) en correspondance à des données captées, générées par au moins un parmi lesdits capteurs (156) et en correspondance à des paramètres de commande respectifs ;
  - (c) des moyens de supervision du processus (130) agencés pour recevoir des données indirectement et/ou directement à partir dudit processus et susceptibles de fonctionner pour surveiller le fonctionnement dudit contrôleur de processus par la définition sélective d'un ou de plusieurs desdits paramètres de commande en fonction desdites données reçues ;

et une structure d'inférence concernant le processus et pour fournir en sortie des données de conseil expertes ; et en ce que

lesdits moyens de supervision du processus (130) sont susceptibles de fonctionner indépendamment dudit contrôleur de processus (154) et comprennent : (i) une pluralité de modules logiciels sensiblement autonomes, chaque module définissant une procédure pour la réalisation d'une tâche souhaitée ; et (ii) des moyens pour appeler, sous des conditions prédéfinies au moins un parmi ladite pluralité de moyens de sous-procédure experte, qui fournissent en sortie lesdites données de conseil expert pour utilisation par lesdits moyens de supervision de processus (130) pour la définition sélective d'un ou de plusieurs des paramètres de commande.

5 25. L'appareil de la revendication 24, dans lequel lesdits moyens de supervision du processus (130) présentent une période maximale d'itération qui est sensiblement plus longue que la période maximale d'itération dudit contrôleur de processus.

10 26. L'appareil de la revendication 24 ou la revendication 25, comprenant une base de données historiques (140) contenant au moins une donnée horodatée concernant le processus.

15 27. L'appareil de la revendication 24, 25 ou 26, dans lequel lesdits moyens de supervision de processus (130) utilisent un traitement par lots qui comprend un état temporisé de sommeil, et la durée dudit état de sommeil est suffisamment grande pour que ledit processus par lots n'occupe pas, en moyenne, plus de 50 % du temps CPU disponible de l'ordinateur sur lequel s'exécutent lesdits moyens de supervision de processus (130) ; et dans lequel la durée dudit état de sommeil est choisie afin d'être suffisamment courte pour que des fluctuations au niveau du processus ne peuvent pas s'écartier vers une situation qui est non maîtrisée par la commande pendant les périodes où ledit processus par lots est en sommeil.

20 28. L'appareil de la revendications 24, 25 ou 26, dans lequel ledit contrôleur de processus (154) fonctionne sensiblement de façon continue en temps réel, et dans lequel un ou plusieurs desdits moyens de sous-procédure experte (120) ne fonctionnent pas en continu en temps réel.

25 29. L'appareil de la revendication 24, 25 ou 26, dans lequel ledit contrôleur de processus comprend de la logique temps réel, et dans lequel un ou plusieurs desdits moyens de sous-procédure experte (120) sont exécutés de façon récurrente en tant que traitements par lots.

30 30. L'appareil selon l'une quelconque des revendications 24 à 29, dans lequel ladite pluralité de moyens de sous-procédure experte (120) sont configurés sous forme d'un ordinateur exécutant un ou plusieurs programmes, comprenant un procédé cyclique effectuant l'échantillonnage répétitif d'une pluralité de signaux correspondant à des entrées, et qui fait des inférences à partir desdites entrées en correspondance à une base de connaissance stockée, et qui fournit des sorties en correspondance auxdites inférences, et passe ensuite dans un état de sommeil qui présente une durée prédéterminée suffisamment longue pour que ledit processus n'occupe pas, en moyenne, plus de 50 % du temps CPU disponible de l'ordinateur et qui est suffisamment courte pour que des fluctuations au niveau du processus ne peuvent pas diverger vers une situation qui n'est pas maîtrisée par la commande pendant des périodes où lesdits moyens de sous-procédure experte sont en sommeil.

35 31. L'appareil selon l'une quelconque des revendications 24 à 30, dans lequel ledit contrôleur de processus (154) comprend un contrôleur analogique.

32. L'appareil selon l'une quelconque des revendications 24 à 31, dans lequel un ou plusieurs desdits paramètres de commande constituent un but ou une valeur cible pour ledit contrôleur de processus (154).

40 33. L'appareil selon l'une quelconque des revendications 24 à 32, dans lequel ledit contrôleur de processus (154) et lesdits moyens de supervision de processus (130) comprennent des traitements qui sont exécutés sur le même système informatique.

45 34. L'appareil selon l'une quelconque des revendications 24 à 33, dans lequel ledit contrôleur de processus (154) et lesdits moyens de supervision de processus (130) sont tous les deux des parties respectives du même système de logiciel.

50 35. L'appareil selon l'une quelconque des revendications 24 à 34, dans lequel ladite pluralité de modules logiciels sont définis par des définitions de données respectives, comprenant des pointeurs vers des premiers moyens pour

effectuer une fonction respective, et, en ce qui concerne au moins certains desdits modules logiciels, des paramètres qui sont à passer auxdits premiers moyens qui sont référencés par pointeur.

5        36. L'appareil selon l'une quelconque des revendications 24 à 34, dans lequel ladite pluralité de modules logiciels est définie par des définitions de données respective, comprenant des pointeurs vers des premiers moyens pour effectuer une fonction respective dans lequel la plupart desdits premiers moyens référencés par pointeur correspondent généralement à un parmi un nombre limité de types de procédure, et dans lequel au moins certains desdits premiers moyens référencés par pointeur contient également des pointeurs supplémentaires vers des deuxièmes moyens qui ne correspondent généralement à aucun dudit nombre limité de types de procédure, et, en ce qui concerne au moins certains desdits modules logiciels, des paramètres à passer vers lesdits premiers moyens référencés par pointeur.

10      37. L'appareil selon l'une quelconque des revendications 24 à 36, comprenant des moyens experts construits (110) configurés pour :

15      (i) suite à une commande, présenter sélectivement à un utilisateur une structure fonctionnelle pour une nouvelle règle pour un moyen sélectionné parmi lesdits moyens de sous-procédure experte (120) ;  
           (ii) suite à une commande, présenter sélectivement à un utilisateur une structure fonctionnelle correspondant à l'entrée fournie par l'utilisateur, à partir de laquelle a été générée une version actuelle desdits moyens des sous-procédures expertes (120) ;  
           (iii) et pour compiler sélectivement une ou plusieurs entrées obtenues de l'utilisateur à partir de ladite structure fonctionnelle pour obtenir une nouvelle version desdits moyens de sous-procédure experte sélectionnés (120).

20      38. L'appareil de la revendication 37, dans lequel ladite structure fonctionnelle présentée à l'utilisateur possède un format sensiblement sous forme de langage naturel qui est facilement compréhensible à un utilisateur qui présente une aptitude technique dans un art prédéterminé mais qui n'est pas forcément compétent dans un langage informatique quelconque.

25      39. L'appareil de la revendication 37 ou 38, dans lequel uniquement des parties limitées de ladite structure fonctionnelle sont susceptibles d'être changées par l'utilisateur.

30      40. L'appareil selon l'une quelconque des revendications 37 à 39, dans lequel ladite structure fonctionnelle comprend des parties susceptibles d'être changées par l'utilisateur qui se présentent différemment audit utilisateur par rapport à d'autres parties de ladite structure fonctionnelle.

35      41. L'appareil selon l'une quelconque des revendications 37 à 40, dans lequel ladite structure fonctionnelle utilise des définitions standardisées d'interface de données telle que l'utilisateur puisse spécifier des données présentant une parmi une pluralité de caractéristiques temporelles prédéfinies.

40      42. L'appareil selon l'une quelconque des revendications 24 à 41, comprenant des moyens de supervision construits (810) qui sont configurés pour :

45      (i) suite à une commande, à présenter sélectivement à l'utilisateur une structure fonctionnelle pour un nouveau module logiciel pour lesdits moyens de supervision de processus (130) ;  
           (ii) suite à une commande à présenter à l'utilisateur une structure fonctionnelle correspondant à une entrée fournie par l'utilisateur à partir de laquelle a été généré un module logiciel actuel desdits moyens de supervision de processus (130) ;  
           (iii) et pour charger sélectivement l'entrée fournie par l'utilisateur à partir de ladite structure fonctionnelle à être utilisée par lesdits moyens de supervision de processus (130).

50      43. L'appareil de la revendication 42, dans lequel lesdits moyens de supervision construits (810) ne permettent pas un accès actif par lesdits moyens de supervision de processus (130) à des données qui correspondent à des entrées nouvelles fournies par l'utilisateur jusqu'au moment où une validation a été effectuée.

55      44. L'appareil de la revendication 42 ou 43, dans lequel lesdits moyens de supervision de processus (130) utilise des moyens permettant un cyclage, et ledit contrôleur de processus (154) fonctionne sensiblement en temps réel.

45. L'appareil selon l'une quelconque des revendications 24 à 44, dans lequel ladite base de connaissance et la

structure d'inférence définissent un système de commande et de contrôle expert (120) qui est sensiblement du type temps réel.

46. L'appareil selon l'une quelconque des revendications 24 à 44, dans lequel ledit contrôleur de processus (154) fonctionne sensiblement en continu et en temps réel et dans lequel un ou plusieurs parmi lesdits moyens de sous-procédure experte (120) ne fonctionnent pas en continu, en temps réel.

47. L'appareil selon l'une quelconque des revendications 24 à 44, dans lequel un ou plusieurs desdits moyens de sous-procédure experte (120) comprennent :

une collection de règles d'inférence consistant en des règles d'extraction dont certaines comprennent respectivement des standards pour l'association d'un attribut avec un objet de façon sélective, en correspondance avec des valeurs d'entrée ;  
 des règles d'analyse, dont certaines respectivement comprennent la logique pour l'association d'un attribut avec un objet de façon sélective en correspondance à un ou plusieurs autres attributs associés à des objets par d'autres règles parmi lesdites règles ;  
 des règles d'action dont certaines comprennent respectivement la logique pour l'exécution d'une commande externe de façon sélective en correspondance à un ou plusieurs autres attributs associés à des objets, par d'autres règles parmi lesdites règles ;  
 un processeur qui est connecté pour recevoir des entrées à partir d'un canal d'entrée, pour exécuter ladite collection de règles d'inférence sur lesdites entrées et pour fournir des sorties vers un canal de sortie en correspondance, dans lequel ledit processeur n'est pas connecté afin de n'effectuer aucun test purement arithmétique lors de l'exécution desdites règles d'analyse, ni lors de l'exécution desdites règles d'action ; et dans lequel ledit processeur n'est pas connecté afin d'évaluer aucune expression logique présentant trois, ou plus de trois termes d'entrée lors de l'exécution desdites règles d'action.

48. Un appareil pour la construction de moyens de sous-procédure experte (120) dans un appareil selon l'une quelconque des revendications 24 à 47, comprenant :

de la logique de génération de règles qui, lorsqu'elle est activée, fournit à l'utilisateur, via une interface interactive, des gabarits pour au moins trois différents types de règles, comprenant :  
 des règles d'extraction, dont certaines comprennent respectivement des standards pour l'association d'un attribut avec un objet, de façon sélective, en correspondance à des valeurs d'entrée ;  
 des règles d'analyse, dont certaines comprennent respectivement la logique pour l'association d'un attribut avec un objet, de façon sélective, en correspondance avec d'autres associations objet/attribut ; et  
 des règles d'action dont certaines comprennent respectivement la logique pour l'exécution d'une commande externe de façon sélective en correspondance à d'autres associations objet/attribut ;  
 dans lequel lesdites règles respectives sont présentées à l'utilisateur sous forme de gabarits qui présentent un format qui est facilement compréhensible par un utilisateur qui n'est pas forcément compétent dans un langage informatique quelconque ;  
 dans lequel uniquement des parties limitées desdits gabarits sont susceptibles d'être changées par l'utilisateur ; et dans lequel ladite logique de génération de règles traduit des entrées fournies par l'utilisateur en correspondance auxdits gabarits pour former un jeu exécutable de règles qui définissent lesdits moyens de sous-procédure experte (120).

49. Un appareil pour la construction d'un système expert dans un appareil selon l'une quelconque des revendications 24 à 47, comprenant :

de la logique de génération de règles, qui, lorsqu'elle est activée, fournit à l'utilisateur des structures fonctionnelles pour des règles en correspondance à un jeu limité de types prédéterminés, dans lequel ladite logique de génération de règles présente lesdites structures fonctionnelles pour la totalité desdites règles sous un format qui est facilement compréhensible par un utilisateur qui n'est pas forcément compétent dans un langage informatique quelconque, et qui n'est pas susceptible d'être changé par l'utilisateur sauf dans des parties limitées ; et dans lequel ladite logique de génération de règles traduit des entrées fournies par l'utilisateur en correspondance auxdites structures fonctionnelles pour former un jeu exécutable complet de règles qui définissent lesdits moyens de sous-procédure experte (120).

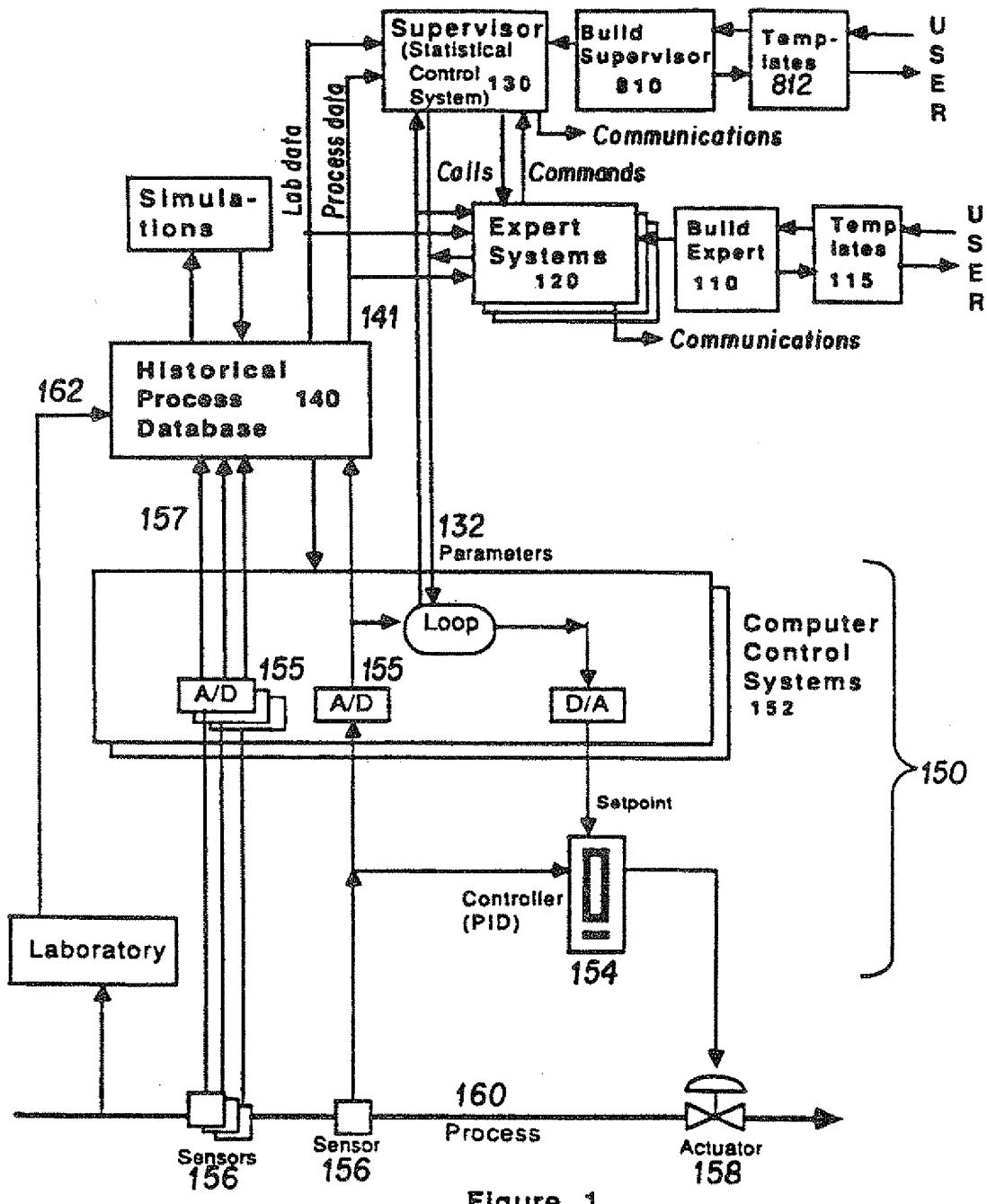
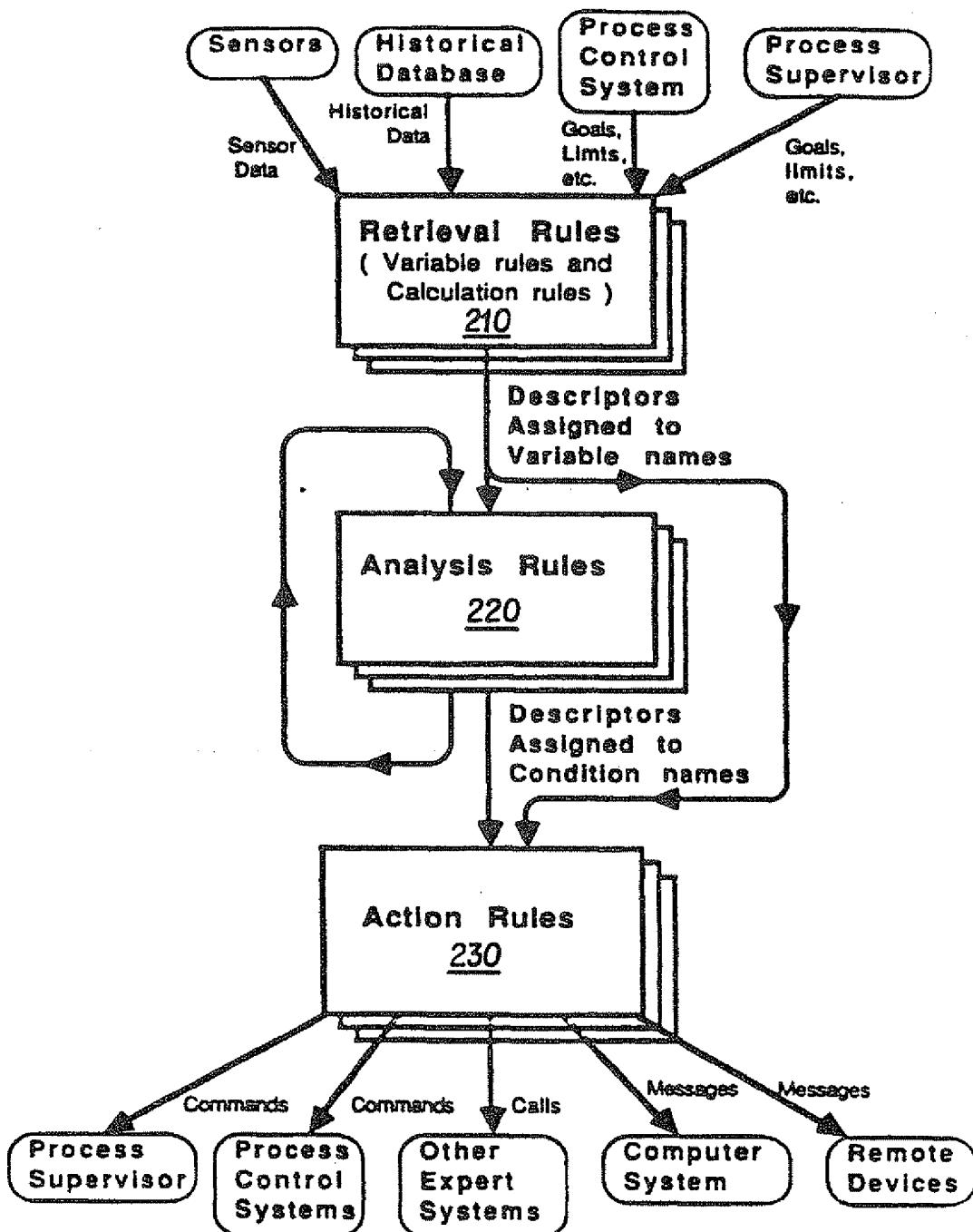


Figure 1



**Figure 2**

Figure 3

Build Expert - Process Variable Calculation Rule Template

Rule Name: XYLENE COLUMN STEAM

Value to be test against the limits below: V1

Status	Value	Operator	Limit	Operator	Limit
MIN		LT.	E2		
MAX		GT.	E1		
MID		GE	E2	LE	E1

**Keypad 7**  
Delete Rule      **Keypad 8**  
Next Page      **Keypad 9**  
Top of Form      **Keypad -**  
Store rule & Exit

Build Expert - Process Variable Calculation Rule Template - P 2

Data Type	Data Index	Time Int - Avg
V1	Goal of Cont Sys loop 8	XYL COL AVG STEAM
V2	Max Manip Value Suprv Block 8	XYL COL AVG STEAM
V3	Min Manip Value Suprv Block 8	XYL COL AVG STEAM
V4		
V5		
V6		
V7		
V8		
V9		
V10		
E1	V2-D3	
E2	V3-D3	
E3	V4-D3	
E4	V5-D3	
E5	V6-D3	
E6	V7-D3	
E7	V8-D3	
E8	V9-D3	
E9	V10-D3	
E10		

**Keypad 7**  
Delete Rule      **Keypad 8**  
→ E1      **Keypad 9**  
Top of Form      **Keypad -**  
Store rule & Exit

Figure 4

Build-Expert Analysis Rule Template																											
Rule Name:	FB TARGET																										
The condition Named: FB TARGET																											
Will have the value: XYLENE COLUMN																											
<table border="1"> <thead> <tr> <th>Variable Rule Name or (NOT)</th> <th>Analysis Condition Name</th> <th>Status</th> <th>Value</th> </tr> </thead> <tbody> <tr> <td></td> <td>FB DIRECTION</td> <td>CUT</td> <td></td> </tr> <tr> <td>AND.</td> <td>.NOT. XYLENE COLUMN STEAM</td> <td>MIN</td> <td></td> </tr> <tr> <td>AND.</td> <td></td> <td>EQ</td> <td></td> </tr> <tr> <td>AND.</td> <td></td> <td>EQ</td> <td></td> </tr> <tr> <td>AND.</td> <td></td> <td>EQ</td> <td></td> </tr> </tbody> </table>				Variable Rule Name or (NOT)	Analysis Condition Name	Status	Value		FB DIRECTION	CUT		AND.	.NOT. XYLENE COLUMN STEAM	MIN		AND.		EQ		AND.		EQ		AND.		EQ	
Variable Rule Name or (NOT)	Analysis Condition Name	Status	Value																								
	FB DIRECTION	CUT																									
AND.	.NOT. XYLENE COLUMN STEAM	MIN																									
AND.		EQ																									
AND.		EQ																									
AND.		EQ																									
		<input type="button" value="Keypad 9"/> <input type="button" value="Keypad 7"/> <input type="button" value="Delete Rule"/> <input type="button" value="Top of Form"/>																									
		<input type="button" value="Keypad -"/> <input type="button" value="Store rule &amp; Exit"/>																									

Figure 5

Build-Expert Action Rule Template		
Rule Name: CHÄNGE XYLÈNE STEAM		
Do the Action below If:		
Variable Rule Name or Analysis Condition Name	Status	Value
FB TARGET	EQ	XYLENE COLUMN
Action Type:	[ 1 ]	
<ul style="list-style-type: none"> <li>1 - Execute a Fortran Statement (may incl a subroutine call)</li> <li>2 - Execute a command procedure</li> <li>3 - Send a Computer Mail Message</li> </ul>		
Fortran Executable Statement, or filename of command procedure		
Status = Select_supv_block ( 3 : 4 , 5 , 0 , 0 , 0 )		
Keypad 7 Delete Rule	Keypad 8 Enter Msg	Keypad 9 Top of Form
Keypad - Store rule & Exit		

Figure 6

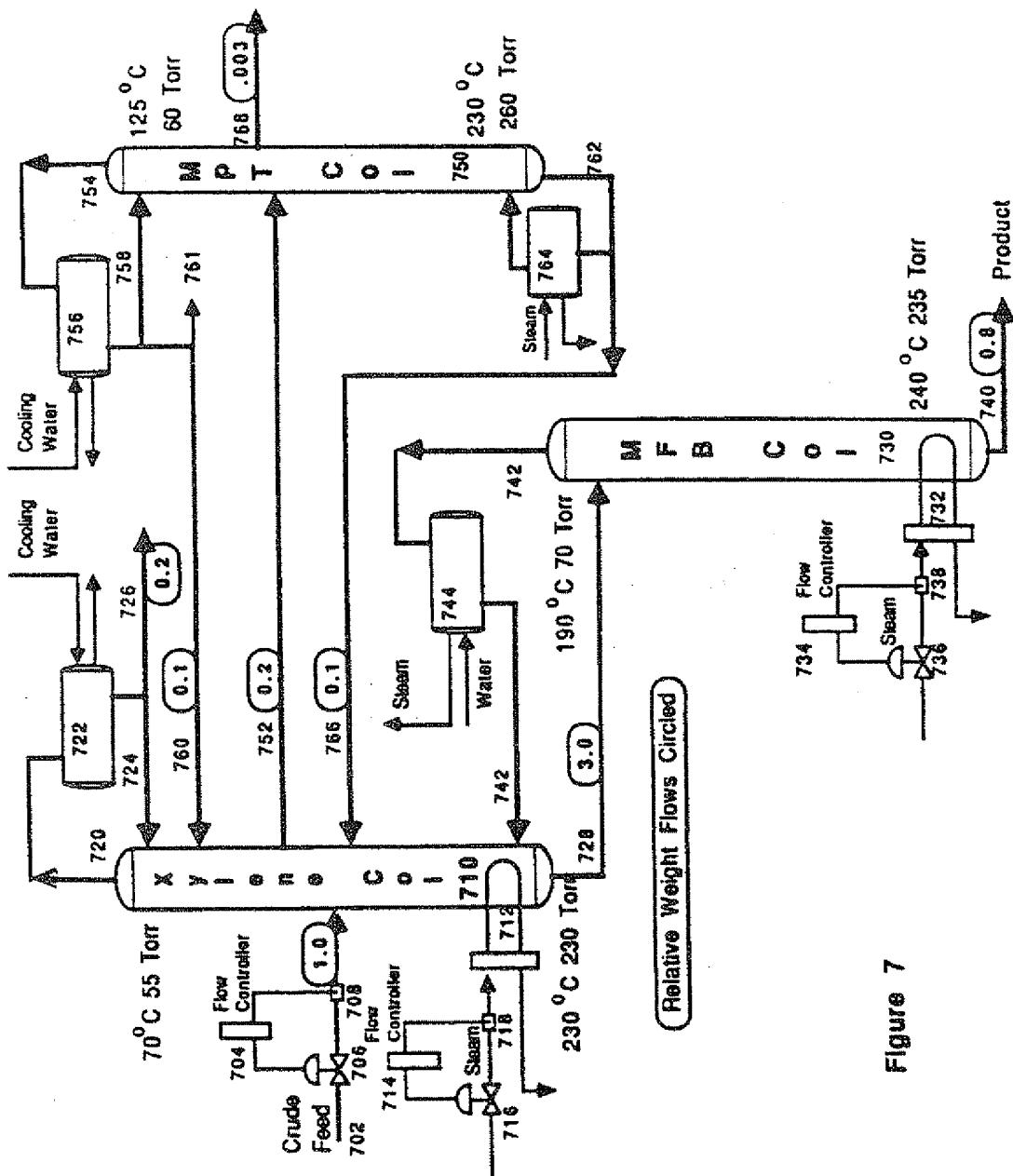


Figure 7

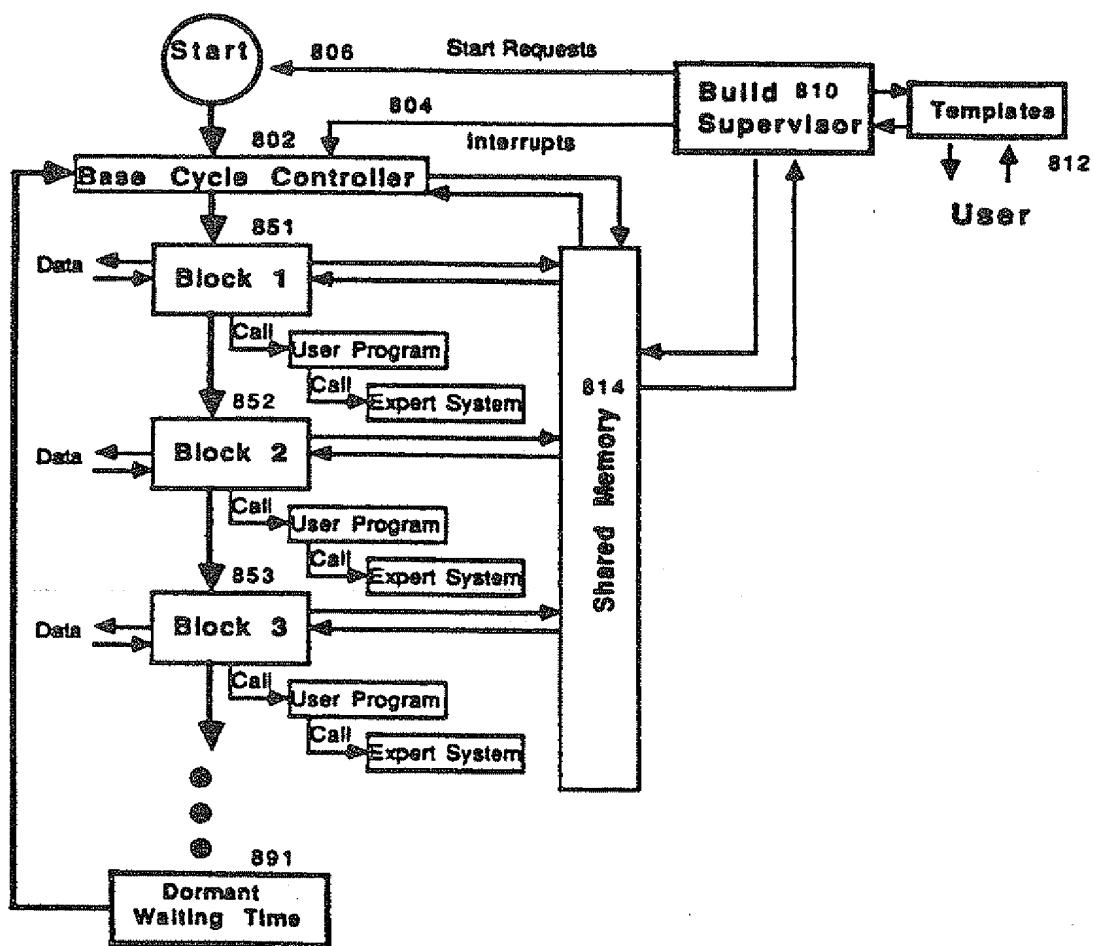


Figure 8

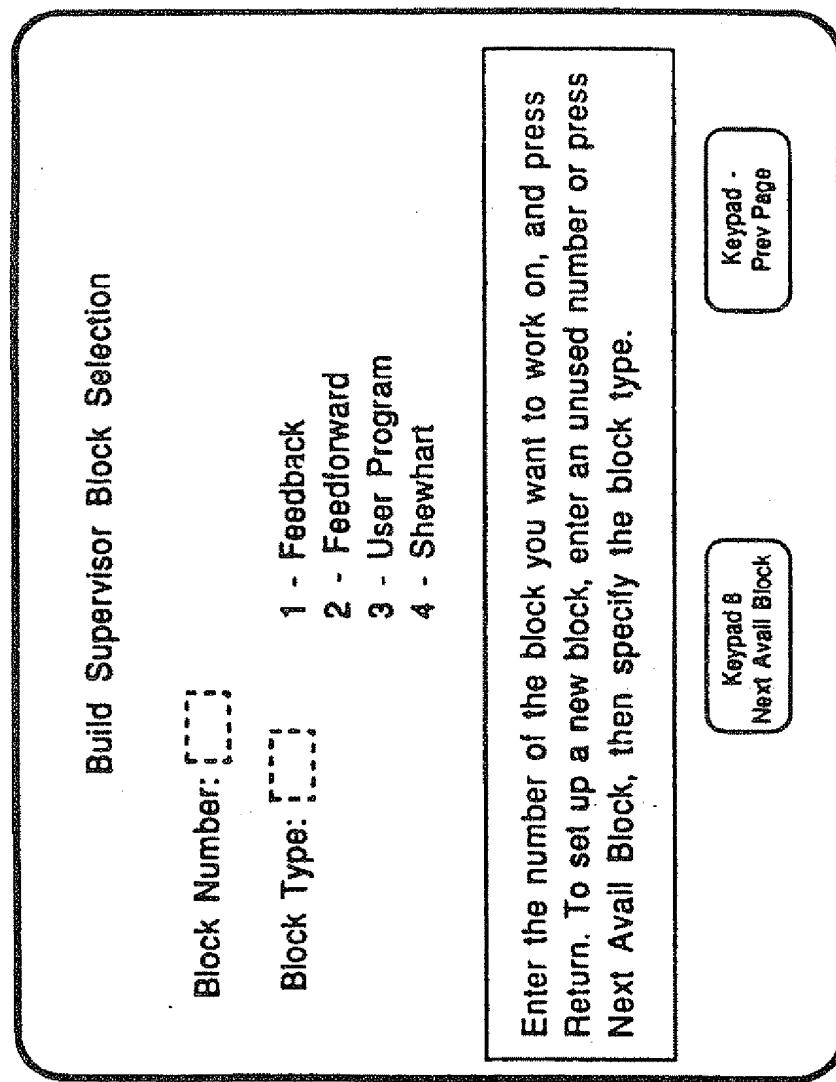


Figure 9

**FEEDBACK CONTROL BLOCK**  
**SETUP TEMPLATE**

Block Number: 1002 Block Owner: Skierik 1012  
 Block Type: Feedback Control Application Name: MFB Control 1016  
 Block Description: DMT Product MFB Shear Test Feedback block acting on Xylene column  
DMT Product MFB Shear Test Feedback block acting on Xylene column  
 Measured Var Type: DMT Product MFB Shear Test Feedback block acting on Xylene column 1016  
 Measured Var # 2390 DMT PRO MFB SHWRT DEVIAT  
 Current Val Hist Dbase Var # 2390 DMT PRO MFB SHWRT DEVIAT  
 Goal: 1004 Goal of DMT Cont Sys Loop # 5 XYL COL AVG STM MPPH  
 Manipulated Var Type: 2 DMT Cont Syst Loop # 6 MFB STAT CONT  
 External Switch Type: 2 DMT Cont Syst Loop # 6 MFB STAT CONT  
 Proportional Gain 1008 0.4000 MPPH / DEVIAT  
 Deadband: 0.0000 DEVIAT  
 Timing Option: 1006 2 Run on Entry of Meas Var  
 Execution Time Intvl: 1000  
 Key Block Number: 116 MPPH  
 Max Manip Delta: 2.0000 MPPH  
 Min Value Manip Var: 40.0000 MPPH  
 Max Value Manip Var: 65.0000 MPPH  
 Min Value Meas Var: 0.0000 DEVIAT  
 Max Value Meas Var: 100.00 DEVIAT  
 Action Log File: MFB Control 1018  
 Block Status: On-selected 1020  

Keypad 7 Keypad 8 Keypad 9 Keypad -  
 Toggle On/Off Next Avail Block Top of Form Store rule & Exit

FIG. 10

**FEEDFORWARD CONTROL BLOCK  
SETUP TEMPLATE**

Block Number: <u>6</u>	Block Type: Feedforward	Block Owner: <u>Steidle</u>
Block Description: <u>DMT Product MFB FF block-Crude feed rate acting on xyene column</u>	Control Application Name: <u>MFB Control</u>	Control Application Name: <u>DMT Product MFB FF block-Crude feed rate acting on xyene column</u>
Measured Var Type: <u>Current Val Hist Dbase Var # 1890</u>	Measured Var Type: <u>Current Val Hist Dbase Var # 1890</u>	Measured Var Type: <u>Current Val Hist Dbase Var # 1890</u>
Manipulated Var Type: <u>2</u>	Manipulated Var Type: <u>2</u>	Manipulated Var Type: <u>2</u>
External Switch Type: <u>0.8000</u>	External Switch Type: <u>0.8000</u>	External Switch Type: <u>0.8000</u>
Proportional Gain: <u>0.0000</u>	Proportional Gain: <u>0.0000</u>	Proportional Gain: <u>0.0000</u>
Deadband: <u>0.0000</u>	Deadband: <u>0.0000</u>	Deadband: <u>0.0000</u>
Timing Option: <u>3</u>	Timing Option: <u>3</u>	Timing Option: <u>3</u>
Execution Time Int: <u>1106</u>	Execution Time Int: <u>1106</u>	Execution Time Int: <u>1106</u>
Key Block Number: <u>2</u>	Key Block Number: <u>2</u>	Key Block Number: <u>2</u>
Max Manip Delta: <u>2.0000</u>	Max Manip Delta: <u>2.0000</u>	Max Manip Delta: <u>2.0000</u>
Min Value Manip Var: <u>40.0000</u>	Min Value Manip Var: <u>40.0000</u>	Min Value Manip Var: <u>40.0000</u>
Max Value Manip Var: <u>65.0000</u>	Max Value Manip Var: <u>65.0000</u>	Max Value Manip Var: <u>65.0000</u>
Min Value Meas Var: <u>50.0000</u>	Min Value Meas Var: <u>50.0000</u>	Min Value Meas Var: <u>50.0000</u>
Max Value Meas Var: <u>720.00</u>	Max Value Meas Var: <u>720.00</u>	Max Value Meas Var: <u>720.00</u>
Action Log File: <u>MFB Control</u>	Action Log File: <u>MFB Control</u>	Action Log File: <u>MFB Control</u>
Block Status: <u>On-deselected</u>	Block Status: <u>On-deselected</u>	Block Status: <u>On-deselected</u>

**Keypad 7**  
**Toggle On/Off**

**Keypad 8**  
**Next Avail Block**

**Keypad 9**  
**Top of Form**

**Keypad -  
Store rule & Exit**

FIG. 11

**Shewhart Statistical Filter Block**  
**SETUP TEMPLATE**

Block Number: <input type="text" value="1"/>	Block Type: Shewhart	Block Description: <input type="text" value="DMT Product MFB Shewhart block"/>	Block Owner: <input type="text" value="Skeik"/>	Block Application Name: <input type="text" value="MFB Control"/>
Filtered Var Type: <input checked="" type="radio" value="4"/> Historical Database Var #	<input type="radio" value="4"/> Historical Database Var #	<input type="radio" value="2"/> Historical Database Var #	<input type="radio" value="1"/> DMT PRODUCT MFB PPM	1236
Deviation Var Type: <input checked="" type="radio" value="4"/> Historical Database Var #	<input type="radio" value="4"/> Historical Database Var #	<input type="radio" value="2"/> Historical Database Var #	<input type="radio" value="2"/> DMT PRD SHRT DEVIAT	
Rule Var Type: <input checked="" type="radio" value="2"/> Historical Database Var #	<input type="radio" value="1"/> DMT PRD SHRT DEVIAT	<input type="radio" value="1"/> DMT PRD SHRT DEVIAT	<input type="radio" value="1"/> DMT PRD SHRT DEVIAT	
External Switch Type: <input checked="" type="radio" value="0"/> Manual	<input type="radio" value="1"/> M	<input type="radio" value="2"/> M	<input type="radio" value="3"/> M	
Aim: <input type="text" value="22000"/> PPM	<input type="text" value="2222"/> PPM	<input type="text" value="25000"/> PPM	<input type="text" value="1222"/> PPM	1228
Sigma: <input type="text" value="2"/> Sigma	<input type="text" value="0.000"/> Sigma	<input type="text" value="0.000"/> Sigma	<input type="text" value="0.000"/> Sigma	1224
Fix Time: <input type="text" value="0 09:00:0"/> HH:MM:SS	<input type="text" value="0 09:00:0"/> HH:MM:SS	<input type="text" value="0 09:00:0"/> HH:MM:SS	<input type="text" value="0 09:00:0"/> HH:MM:SS	1226
Minimum Deviation: <input type="text" value="2200"/> DEVIAT	<input type="text" value="2222"/> DEVIAT	<input type="text" value="2500"/> DEVIAT	<input type="text" value="1222"/> DEVIAT	1230
Maximum Deviation: <input type="text" value="40000"/> DEVIAT	<input type="text" value="4444"/> DEVIAT	<input type="text" value="50000"/> DEVIAT	<input type="text" value="4444"/> DEVIAT	1232
Min Value Meas Var: <input type="text" value="15000"/> PPM	<input type="text" value="15555"/> PPM	<input type="text" value="20000"/> PPM	<input type="text" value="15555"/> PPM	1234
Max Value Meas Var: <input type="text" value="100000"/> PPM	<input type="text" value="100000"/> PPM	<input type="text" value="100000"/> PPM	<input type="text" value="100000"/> PPM	
Action Log File: <input type="text" value="MFB Control"/>	<input type="text" value="On-Record Usr Err"/>	<input type="text" value="On-Record Usr Err"/>	<input type="text" value="On-Record Usr Err"/>	
Block Status: <input type="text" value="On-Record Usr Err"/>	<input type="text" value="On-Record Usr Err"/>	<input type="text" value="On-Record Usr Err"/>	<input type="text" value="On-Record Usr Err"/>	
<b>Keypad 7</b> <input type="text" value="Toggle On/Off"/>				
<b>Keypad 8</b> <input type="text" value="Next Avail Block"/>				
<b>Keypad 9</b> <input type="text" value="Top of Form"/>				
<b>Keypad -</b> <input type="text" value="Store rule &amp; Exit"/>				

FIG. 12

USER PROGRAM BLOCK  
SETUP TEMPLATE

Block Number: <input type="text"/>	Block Owner: <input type="text"/> 1316
Block Type: <input type="text"/>	Control Application Name: <input type="text"/> MFB Control
Block Description: <input type="text"/>	Block for run expert deciding where to take MFB feedback action.
Measured Var Type: <input type="text"/> 4	Current Val Hist Dbase Var # <input type="text"/> 2990 DMT PRD MFB SHWRT DEVIAT
External Switch Type: <input type="text"/> Q	Manual <input type="text"/> Man
Timing Option: <input type="text"/> 5	Fixed Intvl & Msrdr var Entry
Execution Time Intvl: <input type="text"/> 10.00	1332
Key Block Number: <input type="text"/>	
Min Value Meas Var <input type="text"/> 0.0000	DEVIAT
Max Value Meas Var <input type="text"/> 100.00	DEVIAT 1334
Action Log File: <input type="text"/> MFB Control	
Block Status: <input type="text"/> On-selected	

This block will run the user routine Block 2\_user\_routine

Keypad 7  
Toggle On/Off

Keypad 8  
Next Avail Block

Keypad 9  
Top of Form

Keypad-  
Store rule & Exit

FIG. 13

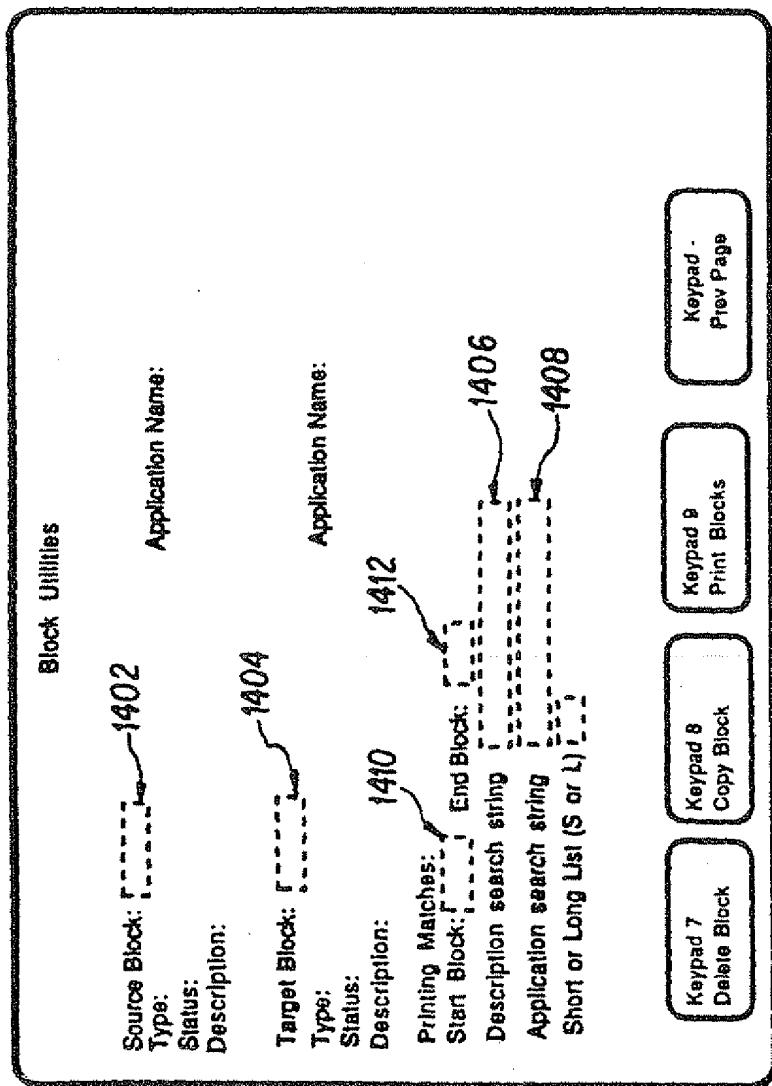


Figure 14

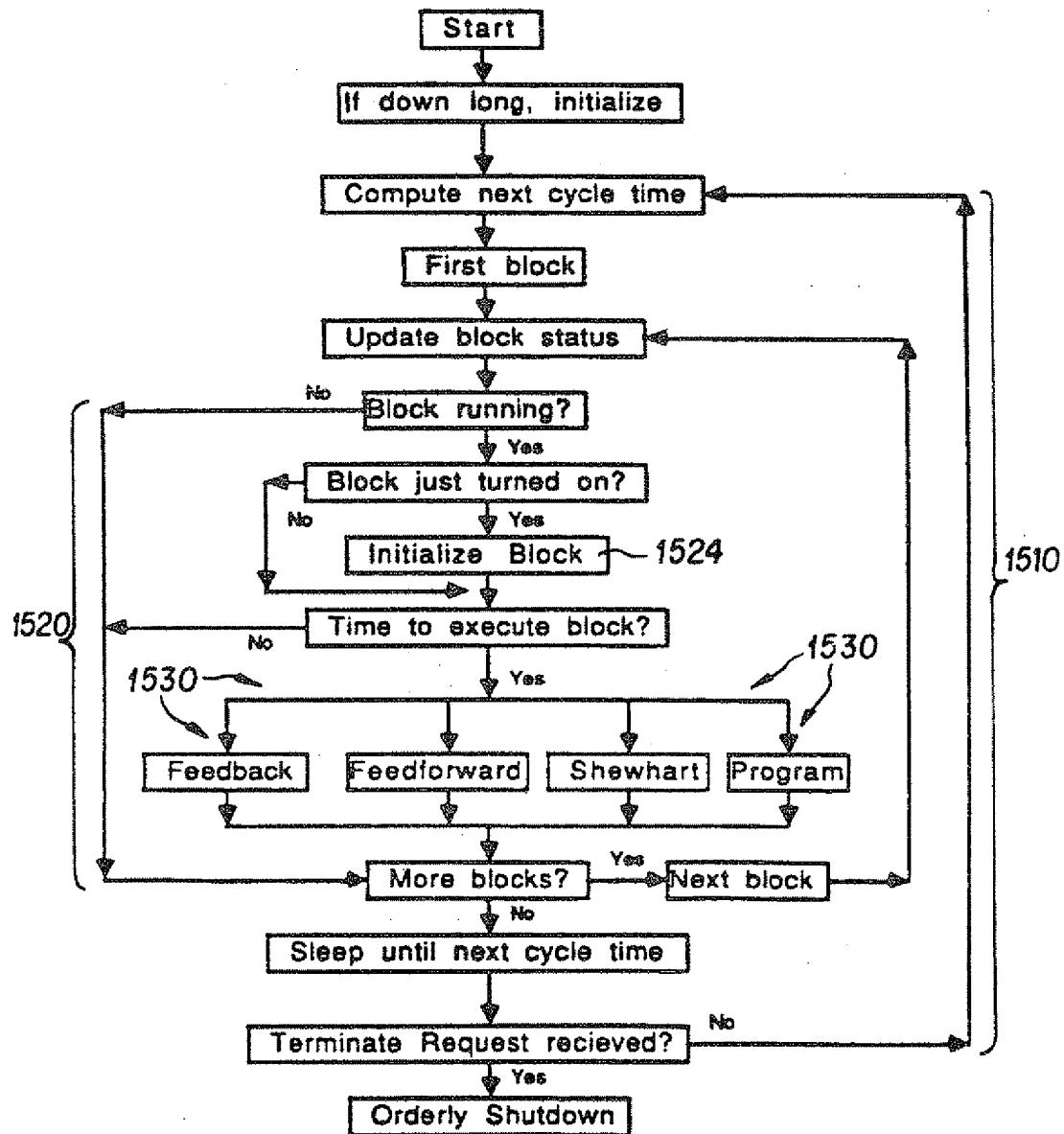


Figure 15

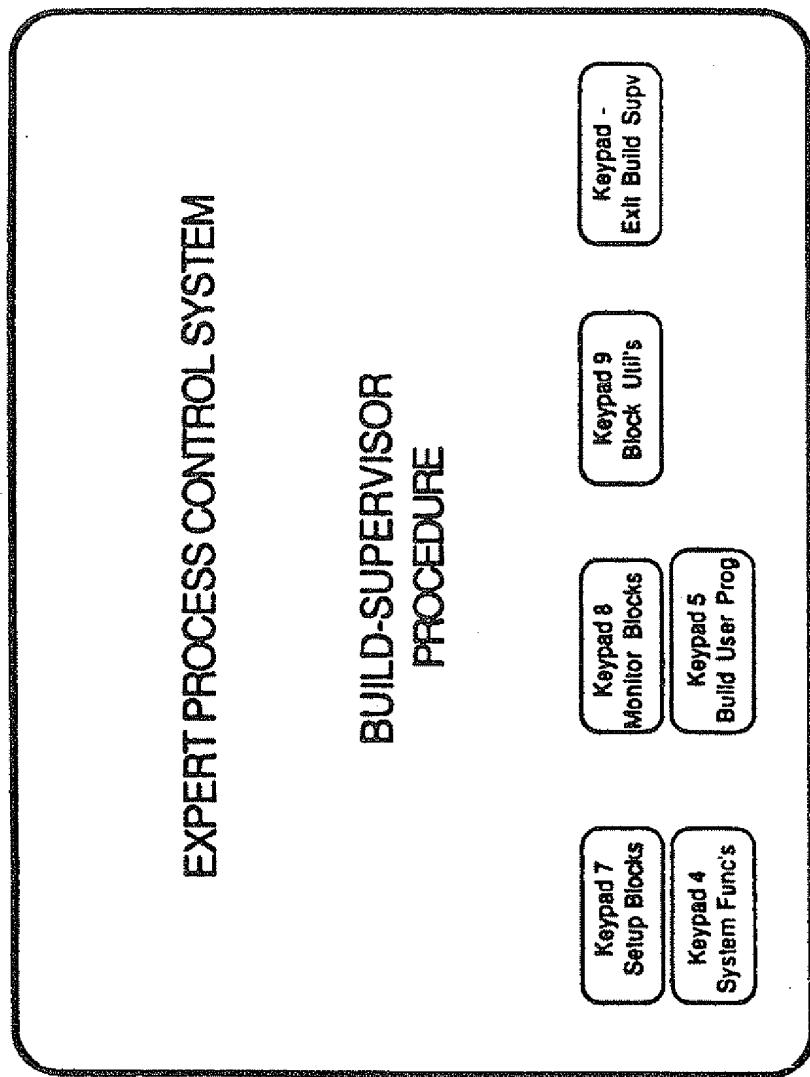


Figure 16

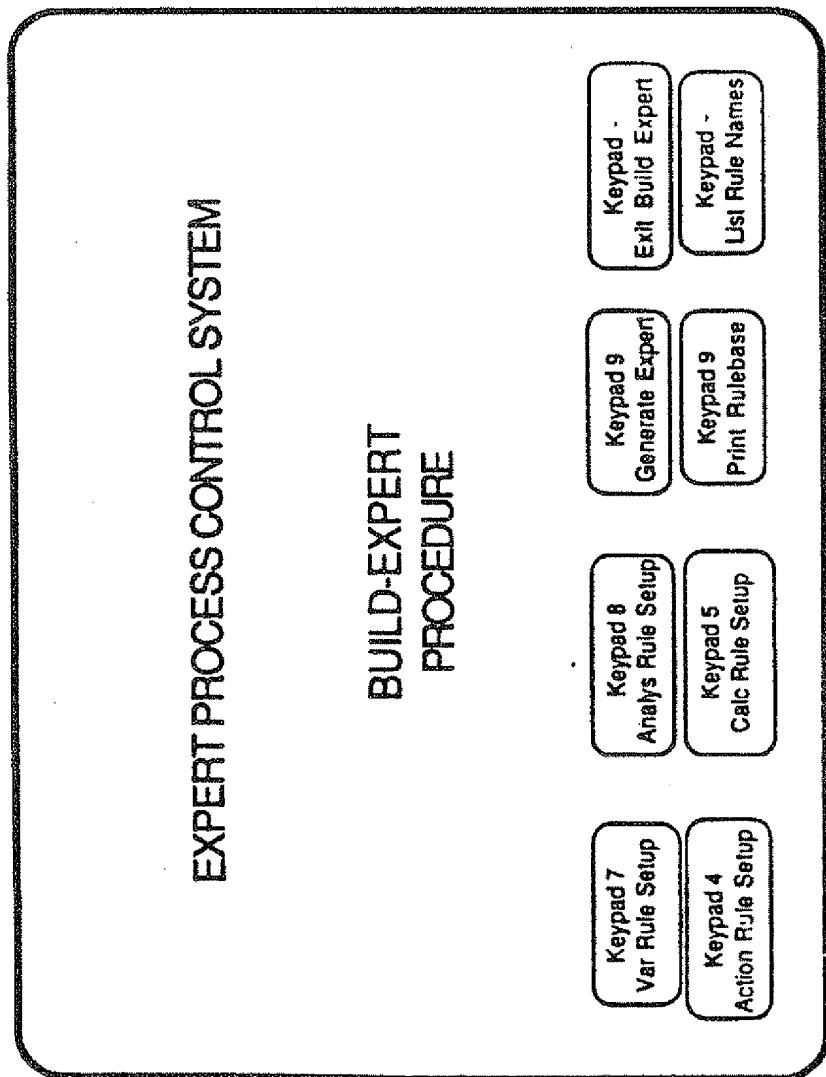


Figure 17

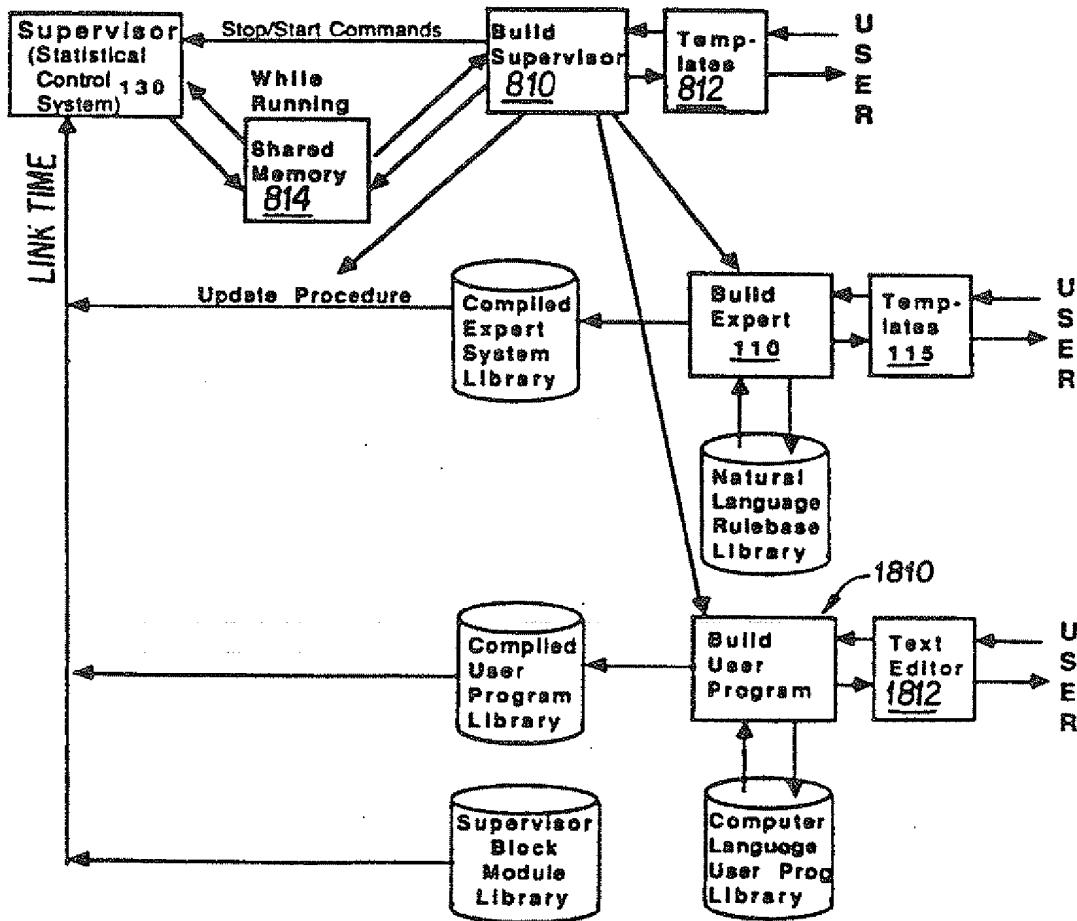


Figure 18